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SUMMARY REPORT

for

NAS10 - 8375

entitled

NETWORK MODEL AND SHORT CIRCUIT PROGRAM FOR THE KENNEDY SPACE CENTER ELECTRIC POWER DISTRIBUTION SYSTEM

(NASA-CR-153051) NETWORK MODEL AND SHORT CIRCUIT PROGRAM FOR THE KENNEDY SPACE CENTER ELECTRIC POWER DISTRIBUTION SYSTEM Summary Report (Georgia Inst. of Tech.) 143 p HC A07/MF A01 CSCL 14B G3/14

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I. INTRODUCTION

This report summarizes two major sub-tasks of contract NAS10-8375, "Computer Model Development for Electrical Power Systems." These subtasks are:

1. System Model Development
2. Short Circuit Program Development

These tasks have been pursued over the preceding ten month interval and have resulted in a complete representation of the power network to the 480 volt level, and a short program tailored to the KSC network implemented on the KSC digital computer system. The explicit summary of these developments is included in the attachments to this report, which are:

1. System one-line diagram coded with model bus designations.
2. Computer print-out of network data base.
3. Computer listing of the short circuit program including short circuit values for the existing network.

This report is intended as a user's guide to the network model and the short circuit program. Emphasis is placed on requirements for updating the model and the program to incorporate modification and additions to the existing KSC network.

Section II of the report describes in detail the assumptions made and the techniques used in determining network model parameter values. Necessary formulae together with sample calculations for determining impedance values for each of the many line and cable configurations utilized at KSC are included. These formulae will provide the necessary data required to update the network for future changes.

Section III describes the short circuit program. Included is a description of the basic computational techniques employed, a flow diagram of the program and a detailed description of operational procedures. A definitive description of program change procedures to incorporate network changes is included.

II. Network Model

Introduction

The objective of this section is to illustrate the methods and formulas used in modeling the system. We have considered it useful to outline the assumptions made where no exact data was available to enable the user to update this model if such data is obtained in the future. We also emphasize that ground faults in electrical cables will, in general, define a band of current levels which is time dependent; the level of fault current increasing with time. In this report, we have chosen the upper boundary of the band because it will certainly define the maximum settings that ground relays should have.

This section is divided into 3 main items, each one subdivided accordingly to its context:

1. Model per unit base
2. Positive-Negative sequence impedances of 3 ϕ power cables
3. Positive-Negative and Zero sequence impedances of overhead lines
4. Zero sequence impedance of 3 ϕ power cables
5. Summary of network configuration and bus designations

Appendix I - Computer programs for zero sequence impedance calculations of 3 ϕ power cables

The model data is an integral part of the short circuit program and may be printed on demand. A print-out of existing parameters is provided as an attachment. Work sheets of impedance calculations are also attached.

A set of single coded line diagrams is attached to provide the interface between the assigned bus codes and the actual network designations. Section V also provides a list of bus codes correlated with network location.

The Indian River Draw Bridge system is an independent system from the Launching Complex or the Industrial Area systems and it must be considered as a separate computer program. Data has been computed in per unit impedances and a set of cards is furnished for this system.

1. Network Model

A. Model Per-Unit Base

a) The following base has been chosen for both the Launch Complex and the Industrial Area

Voltage Base: 13.8 KV
Power Base: 10 MVA
Current Base: 418.86571 AMPS
Impedance Base: 19.044 Ohms.

According to this base the following voltage sources are defined:

Launch Complex = 1.0
Industrial Area = $(.9565217)^2 = (13.2/13.8)^2 = .9149338$

b) Transfer factors for cables impedances at different voltage levels are obtained by the formula =

$$Z_{(p.u.)} = Z_{(ohms)} \times F/_{19.044}$$

where F, the transfer factor, is given as:

$$F = \prod_{i=1}^{n} F_i$$

and

F_i= square of turns ratio of a transformer in the circuit

n= number of transformers between the two different voltage levels.

Typical Transfer Factors are as follows

13.8 KV to 4.16 KV	F= 11.00453
13.8 KV to 2.4 KV	F= 33.0625
13.2 KV to 2.4 KV	F= 30.250
13.8 KV to 480v	F= 826.5625

B. Motor Contribution Modeling

In modeling motors two different criteria has been followed:

Criteria #1: Motors above 600volt.

Criteria #2: Motors at 480volts with code letters

a) Motors above 600 volts

Reactances and resistances values for these motors have been requested from the manufacturers and in only one case

have we been sucessful in obtaining that data at the present time. This information concerns the four 2500 HP synchronous, 1200 SRPM, 4160v-3Ø motors installed in the Launching Complex Utility Annex manufactured by Electric Machinery Co. Sequence impedances are as follows:

Positive Sequence:	0 + j .7253885	per unit
Negative Sequence:	0 + j .777201	"
Zero Sequence:	0 + j .5181345	"
Voltage source:	1.0 + j .0	"

Due to the ground connection shown for all motors in Motor Control Centers A & B, we have assummed a Y grounded connection for these motors and therefore an entry exists for the zero sequence impedances for all motors in the Utility Annex, - If any of the referenced motors have either a Delta or WYE non-grounded connection the zero sequence entry shall be replaced by "Infinite", (See value assigned to "infinite" in the computer program).

All other motors not installed in the Utility Annex have been considered as being Delta connected consequently having an "Infinite" zero sequence impedance. Due to the lack of accurate information, the present model for the induction motors has been implemented accordingly to the locked rotor code or locked rotor current if known.

Example #1

Industrial Area CIF chillers #1, #2, & #3, 688 BHP-2300v-149 FLA-730LRA - 3600RPM- Trane Locked Rotor Reactance

$$= 1.8212 \text{ ohms} = \frac{2300v}{730\sqrt{3}}$$

Transformer: 13200 Δ 2400 Δ F = 30.250

Motor Impedance per unit: $1.8212 \times \frac{30.250}{19.044} = 2.89284$

Motor Impedance:

Positive and Negative Seq:	0 + j 2.89284
Zero sequence:	Infinite
Voltage source:	.9149338

Example #2

Launching complex substation # 924:
2500HP .4160v - 297 FLA-locked rotor code G

Assummed connection: non-grounded WYE
locked rotor code: G
5.6 to 6.29 KVA/HP
Assummed KVA/HP = 6.0
KVA locked rotor = 15000
locked rotor current = 2084 amps
locked rotor reactance = 1.1538 ohms
transformer: 13800 Δ 4160 Y
factor: 11.00453
per unit reactance: $1.1538 \times \frac{11.00453}{19.044} = .66672$

Motor Impedance:

Positive and Negative sequence:	0 + j .66672
Zero sequence:	Infinite
Voltage source:	1.0

Example #3

Launching Complex Utility Annex motor control centers A & B
450HP - 4160v - 63.5 FLA-locked rotor code: C
Assummed connection: grounded WYE
locked rotor code C: 3.55 to 3.99 KVA/HP
Assummed KVA/HP = 3.75
KVA locked rotor = 1687.5
locked rotor current = 234.47 Amps
locked rotor reactance = 10.2556 ohms
transformer: 13800 Δ 4160 Y
factor: 11.00453
per unit reactance: $10.2556 \times \frac{11.00453}{19.044} = 5.9262$

Motor Impedance:

Positive sequence:	0 + j 5.9262
Negative sequence:	0 + j 6.3495
Zero sequence:	0 + j 4.2330
Voltage source:	1.0

Example # 4

Launching Complex Utility Annex Motor Control Centers A
350HP. 4160v- synchronous-39 FLA- 327 RPM-280 KVA
Assummed per unit impedances base on unit KVA rating

Positive sequence:	.01 + j .26
Negative sequence:	.015 + j .2785
Zero sequence:	.01 + j .18

Impedances refered to our base: 10MVA

Transfer factor: 10/.28 = 35.714285
Positive sequence: .35714285 + j 9.285714
Negative sequence: .5357142 + j 9.9464297
Zero sequence: .35714285 + j 6.428571
Voltage source: 1.0

or in ohmic values
Z positive = (.01 + j .26) (4.16)^2/ .28 ohms
Z negative = (.015 + j .2785) (4.16) ^{2}/ .28 ohms
Z zero = (.01 + j .18) (4.16) ^{2}/ .28 ohms

Transfering impedances to 13.8 system
Z positive = (.01 +j .26) (13.8)^2/ .28 ohms
Z negative = (.015 + j .2785) (13.8)^2/ .28 ohms
Z zero = (.01 + j .18) (13.8)^2/ .28 ohms

Expressing in per unit values Z base = (13.8)^2 / 10
Z positive = (.01 + j .26) (10/ .28)
Z negative = (.015 + j .2785) (10/ .28)
Z zero = (.01 + j .18) (10/ .28)

Motor Impedance
Positive sequence: .35714285 + j 9.285714
Negative sequence: .5357142 + j 9.9464297
Zero sequence: .35714285 + j 6.428571
Voltage source: 1.0

Example #5

Launching Complex Utility Annex Motor Control Center B
550HP - 4160v-74 FLA- locked rotor code: B
Assummed connection: grounded WYE
locked rotor code B : 3.15 to 3.54 KVA/HP
Assummed KVA/HP = 3.34
KVA locked rotor: 1837
locked rotor current = 255.25 Amps
locked rotor reactance = 9.4206 ohms
transformer: 13.8 Δ 4.16 Y KV
factor: 11.00453

$$\text{per unit reactance} = 9.4206 \times \frac{11.00453}{19.044} = 5.44365$$

Motor Impedance
Positive sequence: 0 + j 5.44365
Negative sequence: 0 + j 5.83248
Zero sequence: 0 + j 3.88832
Voltage source: 1.0

Example #6

Launching Complex Substation #924 and #1021
200 HP-4160v - 24.1 FLA locked rotor code: H
Assummed connection: non-grounded WYE
locked rotor code H: 6.3 to 7.09 KVA/HP
Assummed KVA/HP = 6.69
KVA locked rotor: 1338
locked rotor current = 185.92 Amps
locked rotor reactance = 12.9336 ohms
transformer: 13.8 Δ 4.16 Y KV
factor: 11.00453
per unit reactance: $12.9336 \times \frac{11.00453}{19.044} = 7.47388$

Motor Impedance

Positive and negative sequence:	0 + j 7.47388
Zero sequence:	Infinite
Voltage source	1.0

Example #7

Launching Complex Substation #924
300HP-4160v - 36.5 FLA-locked rotor code: G
Assummed connection: non-grounded WYE
locked rotor code G: 5.6 - 6.29 KVA/HP
Assummed KVA/HP = 5.94
KVA locked rotor = 1782
locked rotor current = 247.61 Amos
locked rotor reactance = 9.7113 ohms
transformer: 13.8 Δ 4.16 Y KV Factor: 11.00453
per unit reactance: 5.611651

Motor Impedance

Positive and negative sequence :	0 + j 5.611651
Zero sequence:	Infinite
Voltage source:	1.0

Example #8

Launching Complex Substation #927
1000 HP - 4160v -120 FLA-locked rotor code: D (4.0 to 4.49 KVA/HP)
Assummed connection: non-grounded WYE
Assummed KVA/HP = 4.25

KVA locked rotor = 4250
locked rotor current = 590.54 Amps
locked rotor reactance = 4.0719 ohms
transformer: 13.8 Δ 4.16 Y KV
factor: 11.00453
per unit reactance = 2.36165

Motor Impedance

Positive and negative sequence:	0 + j 2.36165
Zero sequence:	Infinite
Voltage source:	1.0

Example #9

Launching Complex Substation #927
500 HP-4160 v -61 FLA-locked rotor code D (4.0 to 4.49 KVA/ HP)
Assummed connection: non grounded WYE
Assummed KVA/HP - 4.25
KVA locked rotor - 2125
locked rotor current = 295.27 Amps
locked rotor reactance = 8.1438 ohms
transformer: 13.8 Δ 4.16Y KV
factor: 11.00453
per unit reactance: 4.7233

Motor Impedance

Positive and negative sequence:	0 + j 4.7233
Zero sequence:	Infinite
Voltage source:	1.0

Example #10

Launching Complex Substation #1020
1000HP-4160v-120 FLA-locked rotor code: E (4.5 to 4.99 KVA/HP)
Assummed connection: non grounded WYE
Assummed KVA/HP: 4.75
KVA locked rotor : 4750
locked rotor current = 660.016 Amps
factor: 11.00453 transformer: 13.8 Δ 4.16 Y KV
locked rotor reactance: 3.6432
per unit reactance: 2.105214

Motor Impedance

Positive and negative sequence:	0 + j 2.105214
Zero sequence:	Infinite
Voltage source:	1.0

Example #11

Launching Complex Substation # 1020
400Hp - 4160v - 49.2 FLA-locked rotor code: F (5.0 to 5.59 KVA/HP)
Assummed connection: non-grounded WYE
Assummed KVA/HP = 5.29
locked rotor KVA = 2116
locked rotor current = 294.02 Amps
locked rotor reactance = 8.1784 ohms
factor: 11.00453 transformer: 13.8 Δ 4.16 Y KV
per unit reactance: 4.725868

Motor Impedance
Positive and negative sequence: 0 + j 4.725868
Zero sequence: Infinite
Voltage source: 1.0

Example # 12

Industrial Area Substation OA. Building M7-355
700Hp-2300v - 207 FLA-locked rotor current = 785 Amps
locked rotor reactance: 1.6936 ohms
per unit reactance = $2.69015 = 1.6936 \times \left(\frac{13.2}{2.4} \right)^2 \times \frac{1}{19.044}$

Motor Impedance
Positive and negative sequence = 0 + j 2.69015
Zero sequence: Infinite
Voltage source: .914338

Example # 13

Industrial Area Substation B and C, building M7-355
700Hp-2300v - 171 FLA - locked rotor current= 785 Amps
locked rotor reactance: 1.6936 ohms Factor = 30.250
per unit reactance = $2.69015 = 1.6936 \times \frac{30.250}{19.044}$

Motor Impedance
Positive and negative sequence = 0 + j 2.69015
Zero sequence: Infinite
Voltage source: .9149338

This concludes the sequence impedance determination for all motors above 600 volts. We have included our assumptions so that if conditions change adjustments can be made. If we finally receive more accurate information concerning these motors it will be sent to your attention.

Concerning the synchronous motors we have always chosen subtransient reactances so that motor contribution during short-circuit conditions will be maximum possible, although in less than 8 Hertz the motors contribution will be based on the transient reactance due to the exponential decay. If the total armature current during the first cycle is desired, the sequence impedances must be divided by $\sqrt{3}$ as by the following formula:

$$
\begin{aligned}
i_{rms}\ (\max) &= \left[\, i_{dc}{}^{2} + i_{ac}{}^{2} \,\right]^{\frac{1}{2}} \\
&= \left[\left(\frac{V\sqrt{2}}{x''} \right)^{2} \right] + \left(\frac{V}{x''} \right)^{2} \Big]^{\frac{1}{2}} \\
&= \sqrt{3}\ \frac{V}{x''}
\end{aligned}
$$

where

V = rated line to neutral voltage

x'' = subtransient reactance

Due to the fast decay of this total armature 1st cycle current, its use is limited to interrupting capacities of circuit breakers.

b) Motors below 600 volts

All of these motors have been considered Delta connected and consequently it has an infinite entry for the zero sequence impedance.

Calculations have been based on the maximum range of the locked rotor code of the machine, as for example a motor having a code letter G that ranges from 5.6 to 6.29 KVA/HP was considered as having a factor of 6.29 for calculati its locked motor current and reactance. As these motors are usually several feet away from the switchgear, their effect over the short-circuit current of the main busses are less critical than with the high voltage motors where its effect can be as high as 70% of the available feeder capacity.

C. Transformers

Transformers are connected Delta-Wye solidly grounded except in a few cases (listed below) where either Delta-Delta or Wye-Wye (solidly grounded both sides) connections have been considered. In the Utility Annex Substation #829, the 4160 Wye connection is grounded thru a resistor of 1.62 ohms.

Transformers in the Launching Complex have primary nominal voltages of 13.8 Kv, consequently they have been considered set in the 13.8 Kv (100%) tap.

Transformers in the Industrial Area have primary nominal voltages of 13.2 Kv (100% tap), 13.2Y7.62 Kv, 13.8 Kv and 24.94Y14.4 Kv. In these cases where the operational voltage of 13.2 Kv differs from the transformer nominal voltage, transformers have been considered to be set in the nearest available tap to the 13.2 Kv level.

Transformers connected to VAB Feeder #609 (operational voltage 13.8 Kv), or to Feeder #211 (operational voltage 13.2 Kv) through 3 x 167 KVA 13.2/13.8 Kv voltage regulators have been considered set at the tap nearest to the 13.8 Kv level.

General:

Per unit sequence impedances have been computed accordingly to the following formula.

$$Z_{pu} = Z\% \times 10^{-2} \times \frac{\text{MVA base}}{\text{MVA unit}} \times \left(\frac{\text{Kv unit}}{\text{Kv base}}\right)^2$$

Then

A. Delta-Wye solidly grounded connection: positive-negative sequence: $0 + Z_{pu}$, Zero sequence: infinite at primary, $0 + j\ Z_{pu}$ at secondary

This has been computed as follows:

Consider that the primary terminal of a transformer is coded as bus 151 and the secondary terminal as bus 152, then two entries exist

Bus Code	Positive-Negative Sequence	Zero Sequence
151-152	$0 + j\ Z_{pu}$	Infinite
Ground 152	Infinite	$0 + j\ Z_{pu}$

B. Wye-Wye connection (solidly grounded both sides)

Positive-Negative & Zero Sequence: $0 + j\ Z_{pu}$

C. Delta-Delta connection

Positive-Negative Sequence: $0 + j\ Z_{pu}$

Zero Sequence: Infinite

Exceptions

Launching Complex Substation #829 Bus Code: 98-100, 99-304 7500 KVA Transformer - 13.3 △ 4.16Y Kv 5.7% impedance grounded thru a resistor of 1.62 ohms

$$Z_{pu} = 5.7\% \times \frac{10 \text{ MVA}}{7.5 \text{ MVA}} \times \left(\frac{13.8}{13.8}\right)^2 \times 10^{-2}$$

$$= .076$$

Grounding Connection: 3 zero sequence secondary currents flowing thru the resistor

Z equivalent = 3 x 1.62 ohms
= 4.86 ohms at the 4.16 Kv side

Impedance referred to the primary side

$$Z_p = 4.86 \text{ ohms} \times \left(\frac{13.8}{4.16}\right)^2$$
$$= 53.482 \text{ ohms}$$

In per unit base

$$Z_{pu} = \frac{53.482}{19.044} = 2.80834$$

Then

Positive-Negative Sequence = 0 + j. 076
Zero Sequence = 2.80834 + j.076

Industrial Area

Orsino Substation - 13.2 Kv output voltage
Main power transformers Bus Codes: 4-8, 4-9, 4-11
10 MVA - 115 Kv△ 13.2YKv solidly grounded - 8.0%

$$Z_{pu} = 8 \times 10^{-2} \times \frac{10}{10} \times \left(\frac{13.2}{13.8}\right)^2$$
$$Z_{pu} = .0731947$$

As this is the system source, it follows that:

Positive-Negative-Zero Sequence = 0 + j.0731947

2.5 MVA - 115 Kv △ 13.2YKv solidly grounded - 7.83%

$$Z_{pu} = 7.83 \times 10^{-2} \times \frac{10}{2.5} \times \left(\frac{13.2}{13.8}\right)^2$$

$$Z_{pu} = j.2865573$$

Positive-Negative-Zero Sequence = 0 + j.2865573

Consequently the impedance contribution by Florida Power Co. will be entered as:

Positive-Negative Sequence: .001189413 + j.0057457842
Zero Sequence: Infinite

Delta-Delta Connection:

Haulover canal (E4-2414) - 3 x 25KVA - 1Ø - 24.94Y14.4/480-240
considered tap 95% - or new nominal voltage of 1368Kv, %Z = 2.0
Bus code 127-128

Turns ratio: $\frac{1368v}{480v} = 28.5$

Also, in this case a Y-Y connection is also possible giving a 480Y277v output for 1368v primary feeder voltage

$$Z_{pu} = 2.0 \times 10^{-2} \times \frac{10}{.075} \times \left(\frac{13.68}{13.8}\right)^2$$
$$= 2.6204$$

Positive-Negative Sequence = 0 + j2.6204
Delta-Delta Zero Sequence = Infinite
Wye-Wye Zero Sequence = 0 + j2.6204

Delta-Delta Connection:

Universal Camera Pad #11 (G5-1011) Bus Code 121-122
3 - 15KVA - 1Ø - 13800/480v - 1.7%Z

$$Z_{pu} = 1.7 \times 10^{-2} \times \frac{10}{.045}$$
$$= 3.77778$$

Positive-Negative Sequence: 0 + j3.77778
Zero Sequence: Infinite

Delta-Delta Connection:

54WTI (L7-988) Bus Code 220-221
3 - 37 1/2 KVA - 1Ø - 13200/480v - 1.6%Z

$$Z_{pu} = 1.6 \times 10^{-2} \times \frac{10}{.1125} \times \left(\frac{13.2}{13.8}\right)^2$$
$$= 1.3012391$$

Positive-Negative Sequence: 0 + j1.3012391
Zero Sequence: Infinite

Wye-Wye Connection:

NASA TWA Tours Maintenance Building Code: 91-90
3-25 KVA - 1Ø - 7620/13200Y 120/240v - 2.3%

$$Z_{pu} = 2.3 \times 10^{-2} \times \frac{10}{.075} \times \left(\frac{13.2}{13.8}\right)^2$$
$$= 2.8057969$$

Positive-Negative-Zero Sequence: 0 + j2.8057969

Wye-Wye Connection:

Indian River Draw Bridge (M3-3) Bus code: 86-87
3-37 1/2 KVA - 1Ø - 7620/13200Y277/480Y - 1.5%

$$Z_{pu} = 1.5 \times 10^{-2} \times \frac{10}{.1125} \times \left(\frac{13.2}{13.8}\right)^2$$
$$= 1.219911$$

Single Phase Transformers

Single phase transformers have been represented as having a positive sequence impedance given by the general formula:

$$Z_{pu} = Z\% \times 10^{-2} \times \frac{\text{MVA base}}{\text{MVA unit}} \times \left(\frac{\text{Kv unit}}{\text{Kv base}}\right)^2$$

The short circuit current at a single phase transformer is represented by a line-ground fault through the transformer positive sequence impedance. Although the 3 Ø symmetrical short circuit program will have a value of short circuit current for every bus, results given by this program shall be disregarded concerning faults of single phase transformers and their corresponding secondary circuits. The short circuit current value for a single phase transformer and its associated secondary circuits is given by the single line to ground short circuit program only.

Example:

1-25 KVA - 1Ø Transformer 13.2 Kv - 2.5%Z

$$Z_{pu} = 2.5 \times 10^{-2} \times \frac{10}{.025} \times \left(\frac{13.2}{13.8}\right)^2$$
$$= j9.149$$

Example:

1-50 KVA - 1Ø Transformer 13.2 Kv
1.4% Z connected to VAB Feeder #609
(13.8 Kv operational voltage) phase C to phase A

Consider transformer connected to tap 13.68Y7.9 Kv

$$Z_{pu} = 1.4 \times 10^{-2} \times \frac{10}{.05} \times \left(\frac{13.68}{13.8}\right)^2$$

$$= j2.7514$$

2. Positive-Negative Sequence Impedances of 3ϕ Power Cables

In calculating the positive-negative and zero sequence impedances of 3ϕ power cables, we have distinguished 3 different types of installations as follows:

A. Cables in fiber ducts or directly buried on earth.
B. Aerial cables.
C. Cables in steel conduits.

For each particular installation we will also distinguish cable construction as follows:

a. Copper or aluminum conductors.
b. Oil-impregnated paper, rubber or cross-linked polyethylene insulation (133% considered on all cables above 1KV).
c. Shielded, belted, or non-shielded (shielded cables considered for all cables above 5KV on PICNJ cables and above 1KV for all BRNJ and XLP cables).
d. Lead or aluminum sheath, or non-sheathed cables.
e. 1 or 3 conductor cables.
f. Single, double armored or non-armored cables.
g. Utilization voltages.

A. Impedance Formulas - General

a) Resistance:

In general resistance calculations can be defined from the following formula:

$$R_{ac} = R_{dc} \times K_t \left[1 + K_1 (K_s + K_p - 1) + K_2 K_\ell + K_c + K_a\right]$$

where

R_{ac} = ac resistance of conductor in ohms/mile

R_{dc} = dc resistance of conductor in ohms/mile

K_t = temperature correction factor

$= 1 + h\,\Delta t$

and

h = .00393 for 100% copper at 20°C (68°F)

= .00403 for 61% aluminum at 20°C

K_1 and K_2 = spacing correction factors

$K_1 = K_2 = 1.0$ for 3 conductor cables

$K_1 = K_2 = 2.0$ for close-triangle 1 conductor cables

$K_1 = 1.7$, $K_2 = 2.0$ for wide-triangle 1 conductor cables

K_s = skin effect ratio as tabulated

K_p = proximity effect

$$= \frac{u\ (ma)}{1 - \frac{a^2}{s^2} \propto (ma) + \frac{a^4 b\ (ma)/s^4}{1 - \frac{a^2}{s^2}}} - 1$$

where

a = radius of conductor
s = spacing of conductors

$$ma = .0636\ (f/R_{dc})^{1/2}$$

for f = frequency in hertz

R_{dc} = dc resistance in ohms/mile

$$u\ (ma) = 1 + \frac{c}{4} - \frac{5c^2}{24} - \frac{3c^8}{8}$$

for $c = \frac{a^2}{s^2} \propto (ma)$

$\propto (ma)$ = bessel function of 1st kind
b (ma) = bessel function of 1st kind

K_ℓ = sheath effect ratio

$$= \frac{3.06 \times 10^{-6}}{R_{dc}\ R_\ell} \left(f\ \frac{n}{m}\right)^2$$

where

n = radius of a circle through the center of conductors
m = mean radius of sheath
R_{dc} = dc resistance of conductor in ohms/mile
R_ℓ = sheath resistance in ohms/mile
K_a = armor effect ratio
= K_ℓ (approximate for 3 conductor cables-not used with 1 conductor cable due to magnetic induction effects

K_c = pipe effect ratio

$$= \frac{(.89D - .115p)}{R_{dc}} \times 5.28 \times 10^{-3}$$

where

D = core diameter of cable in inches
p = pipe mean diameter
R_{dc} = dc resistance of conductor in ohms/mile

b) Reactance

The inductive reactance of cables is a function of cable arrangement, existance of sheath and type of material, and whether or not they are installed in a magnetic duct. As there is not a general expression that could include all variations possible, we will delay reactance considerations to be analized under each particular configuration and type of installation.

The shunt capacitive reactance of cables can be divided into two main categories:

A. Shielded cables
B. Belted sheathed cables

Shielded cables:

For shielded cables, the shunt capacitive reactance can be expressed by the formula:

$$X_1 = X_0 = -j \frac{4.12237}{f \cdot e} \log \frac{v}{a} \quad \text{megohms - mile}$$

where

f = frequency in hertz
e = dielectric constant
= 3.7 for PILC cables (varies from 3.3 to 4.2)
= 5.5 for BRNJ cables (varies from 2.5 to 6.0)
= 2.3 for XLP cables
v = mean radius of shield
a = radius of conductor
X_1 = positive sequence shunt capacitive reactance
X_0 = zero sequence shunt capacitive reactance

Belted cables:

$$X_1 = -j \frac{.597}{f \cdot e} G_1 \quad \text{megohms - mile}$$

$$X_0 = -j \frac{1.79}{f \cdot e} G_0 \quad \text{megohms - mile}$$

where

G_1 = geometric factor for positive sequence

G_o = geometric factor for zero sequence

G_1 and G_o are given by curves as a function of the ratio

$$\frac{T + t}{2a}$$

where

T = thickness of conductor insulation
t = thickness of belt insulation
a = radius of conductor

Curves for geometric factors can be found on page 69 of "Transmission and Distribution Reference Book" and incorporate changes thought to represent today's dielectric constants of BRNJ and XLP cables.

B. Impedances of
Cables in Fiber Ducts or Directly Buried in Earth

a) Resistance:

$$R_{ac} = R_{dc} \cdot K_t \left[1 + K_1 (K_s + K_p - 1) + K_2 K_\ell + K_a\right]$$

a.1. 3 conductor cables

$$R_{ac} = R_{dc} \cdot K_t (K_s + K_p + K_\ell + K_a)$$

PILCNJ Cables: Resistance for these cables have been taken from tabulated values of "Transmission and Distribution Reference Book" appendix tables #5 and #6.

BRNJ Cables: Resistance for these cables have also been taken from tabulated values of "Transmission and Distribution Reference Book" appendix #9.

XLP Cables: Resistance for these cables have also been taken from tabulated values of "Transmission and Distribution Reference Book" appendix #9.

PILCA Double Armor: Resistance values for this cable have been computed as follows:

Cable: 3c - # 2/o - Cu - 15KV - PILC - Double Armor - Shielded conductor
diameter = .323"   a = .1615"
Conductor insulation = 215 mils = .215"
Outside diameter of cable = 2.0225"
GMR_{1c} # 2/o = .151"
GMR_{3c} # 2/o = .386"

Resistance for this cable will be equal to that corresponding to one # 2/o - 3c - Cu - PILCNJ directly buried plus the losses in the double armor.

Resistance of 3c - # 2/o PILCNJ - 15Kv - DB = .51 ohms/mile
Sheath resistance = .981 ohms/mile = R
Sheath thickness = 110 mils = .110"

Calculating sheath effect ratio:

R_{dc} # 2/o = .4282 ohms/mile at 25° C

$$R_{dc} \cdot K = \frac{3.06 \times 10^{-6}}{R} \times 3.6 \times 10^{3} \left(\frac{n}{m}\right)^2$$

Where we assumed n approx = GMR_{3c} = .386"

m = GMR_{3c} + insulation thickness + radius of conductor + thickness of sheath /2.

m = .386" + .1615" + .215" + .055 = .8175"

$$R_{dc} \cdot K_{\ell} = \frac{3.06 \times 3.6 \times 10^{-3}}{.981} \left(\frac{.386}{.8175}\right)^2 \text{ ohms/mile}$$

$$= .002503 \text{ ohms/mile}$$

We have originally assumed that armor losses are approximately equivalent to sheath losses.

Then for double armor $R_{dc} \cdot K_a = 2R_{dc}K_{\ell}$

$R_{dc}K_a$ = .005006 ohms / mile

And the resistance of one 3c . # 2/o - Cu - PILC - double armor 15Kv cable directly buried will be:

R_{ac} = .515006 ohms/mile

a.2. Single Conductor Cables:

$$R_{ac} = R_{dc} \times K_t \, [1 + 2(K_s + K_p - 1)]$$

Considering close-triangle arrangement, non-sheathed cables.

BRNJ Cables: Resistance for these cables have been taken from tabulated values of "Transmission and Distribution Reference Book" appendix table # 9.

XLP Cables: Same as BRNJ.

RHW-USE: Resistance for these cables have been computed based on the National Electric Code 1971 Ed, appendix tables 8 and 9.

Example:

Cable: 3 single copper conductors ≠ 4 - BRNJ - shielded 5Kv installed in 4" fiber duct.

Outside diameter of cable = .67"
Conductor radius = a = .116"
GMR_{1c} = .08404"

Insulation = 10/64" = 156 mils = .156"
R_{dc} = .259 ohms/1000' = 1.36752 ohms/mils

$K_t = 1.154$ for 65° C

$K_s = 1.00013$

$$K_p = 6 \left(\frac{GMR}{GMD} \right)^2 (K_s - 1)$$

From page 2-5 of "Underground System Reference Handbook".

Where:

GMD = geometric mean distance

$$GMD = (S_1 \cdot S_2 \cdot S_3)^{1/3}$$

Where:

S_1, S_2, S_3 are the respective spacing of the 3 conductors' centers from each other.

Generally $S_1 = S_2$ = outside diameter.

S_3 depends on the ratio between the duct and conductor diameter, in this case we have graphically found $S_3 = 1.61\ S_1$.

$$GMD = .67'' \ (1.61)^{1/3}$$
$$= .78591''$$

$$K_p = 6 \times 0.00013 \left(\frac{.08404}{.78591}\right)^2 = .000010062$$

$$R_{ac} = 1.36752 \times 1.154 \ [1 + 2(1.00013 + .000010062)]$$

R_{ac} = 1.57948 ohms/mile at 65° C

b). Reactance

Reactance of 3 conductor or single conductor, non-sheathed cables in non-magnetic conduit or directly buried is given by the formula:

$$X_1 = .2794\ K \log \frac{GMD}{GMR_{1c}}$$

Where K is the random spacing factor:

K = 1.0 for 3 conductor cables
K = 1.2 for 1 conductor cables

For sheathed cables, a reduction in reactance is produced by the induced currents in the shield and sheath structures.

For sheathed cables, this decrement in reactance can be approximated by the formula:

$$X_{ac} = K_d X_1$$

and

$$K_d = 1 - \frac{X_s}{X_1} \cdot \frac{X_s^2}{R_\ell^2 + X_s^2}$$

Where

X_{ac} = apparent reactance

X_s = .2794 log $\frac{d}{g}$

Where

d = (core diameter + sheath thickness)/2

g = $\frac{\text{core diameter}}{2}$ - insulation thickness - radius of conductor

Due to the resistance of lead sheaths, the decrement of reactance due to the induced sheath currents is very small approximately of the order of 1 to 5%.

b.1. 3 Conductor Cables:

PILCNJ Cables: Reactance values for these cables were taken from tabulated values of "Transmission and Distribution Reference Book" appendix tables # 5 and # 6.

XLP and BRNJ Cables: Reactance values for these cables were computed accordingly to the above given formula.

Example:

3c - CR - Cu - # 1/o - BRNJ 15 Kv shielded in non-magnetic duct on directly buried in earth

Conductor diameter = .373"
Conductor radius = .187"
Insulation thickness = .297" = 19/64" (assumed insulation to be equal to 1 conductor cable at 133%)
GMR_{1c} = .14117
$GMD = S_1 = S_2 = S_3$
S_1 = .187" + 2(.297") + .006" (shield) + .003125"
= 1.004"

$$X_1 = .2794 \log \frac{1.004}{.14117}$$

X_1 = .238046 ohms/mile

PILCA - double armor: Reactance values for this cable have been computed as follows:

Cable: 3c - # 2/o - Cu - CS - 15Kv - PILC - double armor - shielded
GMR_{1c} = .151"
Conductor radius = a = .1615"
Insulation = 215 mils = .215"

Reactance without armor = .188 ohms/mile
Reactance with armor = 1.2 x .188
= .2256 ohms/mile

Where 1.2 is a correction factor for magnetic binders on 3 conductor cables by IPCEA Standard, August 4, 1933.

b.2 <u>Single Conductor Cables</u>

$$X_1 = .2794 \times 1.2 \log \frac{GMD}{GMR_{1c}}$$

XLP and BRNJ: Reactances for these cables have been computed using the above given formula and graphically determination of conductor spacing inside duct.

RHW-USE: Reactances for these cables have been computed using the above given formula and graphically determination of conductor spacing inside duct.

Example:

Cable: 3 single copper conductors # 4 - CR - BRNJ - shielded - 5KV - installed in 4" fiber duct.

Outside diameter of cable = .67"
Insulation = 10/64" = .156"
GMR_{1c} = .08404"
GMD = .78591" (see resistance - single conductor cables in fiber ducts or directly buried in earth)

$$X_1 = .2794 \times 1.2 \log \frac{.78591}{.08404}$$
$$= .3257 \text{ ohms/mile}$$

Example:

Cable: 3 single copper conductors 350 MCM - CR - XLP - 15 Kv - shielded - installed in 4" fiber duct.

Outside diameter = 1.45"
Diameter of conductor = .681" a = .3405"
Insulation = .215" (133%)
Jacket = .08"
GMR_{1c} = .26145"
$$GMD = (S.\ S.\ (S + .615))^{1/3} = S\ (1.61)^{1/3} = 1.1735$$

Where S = outside diameter

GMD = 1.725"

$$X_1 = .2794 \times 1.2 \log \frac{1.725}{.26145}$$

$$X_1 = .275 \text{ ohms/mile}$$

C. Impedances of Aerial Cables:

a. Resistance

Resistance calculations have been based on the general resistance formula

$$R_{ac} = R_{dc} \cdot K_t\ [1 + K_1\ (K_s + K_p - 1) + K_2K_\ell + K_c + K_a]$$

Where K_c has been deleted for cables suspended on a messenger.

a 1.3 Conductor Cables:

$R_{ac} = R_{dc} \cdot K_t\ (K_s + K_p + K_\ell)$ For non-armored cables

PIAC Cables: Resistance values have been computed using the above formula as follows:

Example:

Cable: 3 conductor copper # 4/o - CS - 15Kv PIAC (aluminum sheath) shielded - suspended on messenger

Core diameter = 1.917"
Conductor diameter = .41" a = .205"
Conductor insulation = .215" (133%).
GMR_{1c} = .191"
GMR_{3c} = .446"
R_{dc} = .26875 ohms/mile at 25°C
R_{dc} = .31 ohms/mile at 65°C
$K_s + K_p = 1.0034 + .001059 = 1.00446$
Aluminum resistance = 2.6548 ohm . CM x 10^{-6}
Lead resistance = 22 ohm . CM x 10^{-6}
Thickness of sheath = 115 mils = .115"
Aluminum resistance = .12067272 Lead resistance

We have assumed (no exact data available) that lead sheath thickness will be equivalent to aluminum sheath thickness.

Resistance of the lead sheath of one 3c - Cu- # 4/o - CS - PILCNJ - 15Kv = R_ℓ = .855 ohms/mile

Resistance of an equivalent thickness aluminum sheath = $R_{a\ell}$ = .855 x .12067272

7 = GMR_{3c} = .446"
m = GMR_{3c} + insulation thickness + radius of conductor + thickness of sheath /2
m = .446" + .215" + .205" + .0575"
= .9235"

$$R_{dc}K_\ell = \frac{3.06 \times 3.6 \times 10^{-3}}{.12067272 \times .855} \left(\frac{.446}{.923}\right)^2 \text{ ohms/mile}$$
$$= .025 \text{ ohms/mile}$$

$R_{ac} = R_{dc}\ (K_s + K_p) + R_{dc}K_{\ell}$ ohms/mile

$= .31\ (1.00446) + .025$ ohms/mile

$= .3353$ ohms/mile

There

Resistance at 65°C of 3 conductor - copper - CS - # 4/0 PIAC - 15KV - shielded in 4" fiber duct or directly buried in earth = .3353 ohms/mile

a.2. Single Conductor Cables:

$$R_{ac} = R_{dc} \cdot K_t\ [1 + 2(K_s + K_p - 1) + 2K_{sh}]$$

XLP Cables: Resistance values for these cables have been computed as follows:

Example:

Cable: 3 single conductors - copper - 350 MCM - XLP 15 Kv - shielded - suspended on messenger.

Core diameter = 1.195"
Outside diameter = 1.45"
Conductor diameter = .681" a = .3405"

$R_{dc} = .162624$ ohms/mile at 25°C

$= .187668$ ohms/mile at 65°C

$GMR_{1c} = .26145"$

$K_s = 1.009$

$GMD = 1.173 \times 1.45" = 1.725"$

$$K_p = 6\ \left(\frac{.26145}{1.725}\right)^2\ (1.009 - 1)$$

$K_p = .00124$

a.3. Shield Resistance Factor

Resistance losses due to induced currents in the shielding assembly can be expressed similarly as sheath losses by the formula

$$R_{dc} \cdot K_{sh} = 555/R_s \quad \text{microhms/ft}$$

Where K_{sh} = resistance increment factor due to shield currents

R_s = shield resistance in microhms/ft

We have considered shielding to be composed of helically wound copper wires for which the resistance can be expressed as

$R_s = 963D + 45$ microhms per ft. at 25°C

Where D = Core diameter

There

$$R_s = 1150.79 + 45 \text{ microhms/ft at } 25^\circ C$$
$$= 1380 \text{ microhms/ft at } 65^\circ C$$

$$R_{dc} \cdot K_{sh} = 555/1380 \text{ microhms/ft}$$
$$= .402 \text{ microhms/ft}$$
$$= .002123 \text{ ohms/mile}$$

$$R_{ac} = .187668 \, [1 + 2 \, (1.009 + .00124 - 1)] + .004246 \text{ ohms/mile}$$
$$= .195765 \text{ ohms/mile}$$

Resistance of 3 single copper conductors 350 MCM - XLP 15Kv - shielded - suspended on a messenger = .196 ohms/mile at 65°C.

b. <u>Reactance</u>

b.1. <u>3 conductor PIAC cables:</u> Reactance values for these cables have been computed according to the formula

$$X_{ac} = .2794 \, K_d \log \frac{GMD}{GMR_k} \quad \text{ohms/mile}$$

Where

$$K_d = 1 - \frac{X_s}{X_1} \cdot \frac{X_s^2}{R_\ell + X_s^2}$$

$$X_s = .2794 \log \frac{d}{g} \quad \text{ohms/mile}$$

d = (core diameter + sheath thickness) /2
g = (core diameter) /2 - insulation thickness - radius of conductor

Example:

Cable: 3 conductor copper # 4/o - CS - PIAC 15KV (aluminum sheath) shielded - suspended on messenger

Core diameter = 1.917"
Conductor diameter = .417" a = .205"
Insulation = .215" (133%)
GMR_{1c} = .191"
Aluminum sheath = .115"
Resistance of aluminum sheath = .1032 ohms/mile

$$GMD = \text{conductor diameter} + 2(\text{insulation}) + \text{shielding} + \text{spacing factor}$$
$$= .417'' + 2(.215'') + .006'' + .03025''$$
$$GMD = .9''$$

$$d = (1.917'' + .115'')/2$$
$$= 1.016''$$

$$g = \frac{1.917''}{2} - .215'' - .205''$$
$$= .538''$$

$$X_s = .2794 \log \frac{1.016}{.538} \text{ ohms/mile}$$
$$= .07711 \text{ ohms/mile}$$

But for compact sector (CS) conductors, reactance has a decrement fact. r by IPCEA Standard, August 1933, of .975 for 250 MCM and smaller cables.

$$X_s = .975 \times .07711 \text{ ohms/mile}$$
$$= .0751 \text{ ohms/mile}$$

And

$$X_1 = .2794 \log \frac{GMD}{GMR_{1c}} \text{ ohms/mile}$$
$$= .2794 \log \frac{.9}{.191} \text{ ohms/mile}$$
$$= .1881 \text{ ohms/mile}$$

$$K_d = 1 - \frac{(.0751)^3}{.1881} \cdot \frac{1}{(.1032)^2 + (.0751)^2}$$
$$K_d = .862$$
$$X_{ac} = .862 \times .1881$$
$$= .162 \text{ ohms/mile}$$

Reactance of one 3 conductor copper - CS - # 4/o - PIAC 15Kv - shielded cable suspended on messenger = .162 ohms/mile

The behavior of induced currents in the lead sheath of one 3c # 1 - PILCNJ 15Kv has been computed using the above method and results are as follows:

$$R_\ell = .900 \text{ ohms/mile}$$
$$K_d = .9964$$
$$X_1 = .2288 \text{ ohms/mile}$$
$$X_{ac} = .228 \text{ ohms/mile}$$

b. 2. XLP Single Conductor Cables: Reactance values for these cables have been computed using the general formula

$$X_1 = .2794 \log \frac{GMD}{GMR_{1c}} \quad \text{ohms/mile}$$

Where GMD = $(1.05)^{1/3}$ x outside diameter
Considering that the spacing of the helically twisted conductors is not exactly symmetrical.

Calculations done for XLP - 15Kv - shielded cables have resulted in values very close to published data in "Distribution Systems" appendix table 8 by Westinghouse Electric Company, consequently the positive sequence impedance for these cables have been taken from such publication.

Example:

Cable: 3 single conductors copper # 4/o, XLP 15Kv - shielded - suspended on messenger.

Outside diameter = 1.32"
GMR_{1c} = .19989"
GMD = 1.02 x 1.32"
= 1.3464"

$$X_1 = .2794 \log \frac{1.3464}{.19989} \quad \text{ohms/mile}$$
$$= .2313823 \quad \text{ohms/mile}$$

Reactance of 3 - 1c - # 4/o - XLP 15Kv suspended in messenger = .2313823 ohms/mile

D) Cables in Steel Conduit:

a. Resistance:

$$R_{ac} = R_{dc} \cdot K_t \,[1 + K_1 \,(K_s + K_p - 1) + K_2 K_x + K_a + K_c]$$

Where

$K_1 = K_2 = 1.0$ for 3 conductor cables
$K_1 = K_2 = 2.0$ for 1 conductor cables in close triangular configuration

a.1. <u>3 Conductor Cables</u>

PIAC and PILCNJ Cables: Resistance values for these cables have been computed adding the steel conduit contribution to the tabulated resistance for cables in fiber ducts or directly buried in earth.

Example:

Cable: 3 conductor copper - CS - # 4/o - PILCNJ 15Kv - shielded in 4" steel conduit.

Core diameter = 1.953" = D

$$R_{dc} \cdot K_c = (.89\ D - .115p) \times 5.28 \times 10^{-3} \quad \text{ohms/mile}$$
$$= (.89 \times 1.953 - .115 \times 4.0) \times 5.28 \times 10^{-3} \quad \text{ohms/mile}$$
$$= .00675 \quad \text{ohms/mile}$$

Resistance of cable in fiber duct = .326 ohms/mile
Resistance of cable in steel conduit = .332 ohms/mile

The following formula will also give approximate values of the steel pipe resistance contribution.

$$R_{dc} \cdot K_c = (.36r + .185p) \times 10^{-2} \quad \text{ohms/mile}$$

Where r = outside radius of sheath

Example:

Cable: 3 conductor copper 500 MCM - CS - PILCNJ 15Kv - shielded in 4" steel conduit.

Core diameter = 2.426
Sheath thickness = .130"
Insulation thickness = .215"

$$r = \frac{1}{2}(2.426") + .130"$$
$$= 1.343"$$

$$R_{dc} \cdot K_c = (.36 \times 1.343 + .185 \times 4) \times 10^{-2} \quad \text{ohms/mile}$$
$$= .01223 \quad \text{ohms/mile}$$

Using the first formula

$$R_{dc} \cdot K_c = (.89 \times 2.426 - .115 \times 4) \times 5.28 \times 10^{-3} \quad \text{ohms/mile}$$
$$= .00897 \quad \text{ohms/mile}$$

Resistance of cable in fiber duct = .149 ohms/mile
Resistance of cable in steel pipe = .159 ohms/mile

a.2. <u>Single Conductor Cables:</u>

BRNJ and XLP Cables: Resistance values for these cables have been computed adding the steel conduit contribution to the tabulated resistance for cables in fiber duct or directly buried in earth.

Example:

Cable: 3 single conductor copper 500 MCM - BRNJ 5 Kv - shielded.

Core diameter = 1.244"
Insulation thickness = .172"

$$r = \frac{1}{2}\,(1.244") + .026" \text{ (shield)}$$

$$r = .648"$$

$$R_{dc} \cdot K_c = (.36x\ .648" + .185 \times 4") \times 10^{-2} \text{ ohms/mile}$$

$$= .010 \text{ ohms/mile}$$

Resistance of cables in fiber duct = .1413 ohms/mile
Resistance of cables in steel pipe = .1513 ohms/mile

This result is comparable to the IPCEA V-C specifications that list AC/DC resistance ratios for cables in metallic conduit. Differences between results is of the order of .00267 ohms/mile or 1.76% difference without taking into consideration the shielding resistance contribution.

RHW-USE Cables: Resistance values for these cables have been computed using the ratio between AC/DC resistance factors as published by the National Electrical Code 1971 Ed. Table 9 and calculated skin and proximity effect factors.

Example:

Cable: 3 single conductors copper 350M - RHW-USE 600V in 4" conduit.

Outside diameter = 1.05"
Insulation thickness = .094"

$$GMR_{1c} = .26145"$$

$$R_{DC} = .0308 \text{ ohms/1000 ft.}$$

$$GMD = 1.183 \times 1.05" = 1.245$$

$$ma = .0636\left(\frac{60}{.0308 \times 5.28}\right)^{1/2}$$

$$= 1.22$$

$K_s = 1.01$

$K_p = 6 \left(\frac{GMR_{1c}}{GMD} \right)^{1/2} (K_s - 1)$

$\quad = .00277$

$K_s + K_p = 1.01277$

$R_{AC} = R_{DC} (1 + 2 \times .01277)$

$R_{AC} = .0308 \times 5.28 \times 1.153$ ohms/mile

$\quad = .19225$ ohms/mile at 65°C

Resistance of cable in fiber duct at 65°C = .19225 ohms/mile

From NEC Table 9: $\frac{R_{AC}}{R_{DC}} = 1.08$ for cables in magnetic duct

Considered $1.08 = 1.027 + K_c$

$K_c = .0528$

Pipe contribution = .0528 x 5.28 x .0308 x 1.153 ohms/mile

= .0098 ohms/mile

Resistance of cable in steel conduit = .20205 ohms/mile

b) Reactance

b.1. 3 Conductor Cables: Reactance values for these cables have been computed using the pipe cables formula given in "Underground Systems Reference Book" Edison Electrical Institute.

$$X = .053f \log \frac{D_1}{D_s} \quad \text{ohms/mile}$$

Where

f = frequency in hertz

$D_1 = 1.3$ GMD

$D_s = F_s \cdot 2a$

a = radius of conductor

F_s = decrement factor of conducting area due to apparent skin effect. F_s is obtained graphically as a function of the combined AC/DC resistance ratio.

$F_s = f (W_s)$

Where

$W_s = \left(\frac{R_s - 1}{R_s}\right)^{1/2}$ $\qquad$ R_s = AC/DC resistance ratio

PILC and PILCNJ Cables: Reactance values for these cables in steel conduit have been computed accordingly to the above formulas.

Example:

Cable: 3 conductor copper 350 MCM - CS - PILCNJ 15 Kv - shielded in 4" steel conduit.

Conductor diameter = .539" a = .2695"
Core diameter = 2.208"
Insulation = .215"
AC/DC resistance ratio = R_s = 1.08
GMD = .539" + 2(.215") + .006" + .03125"
= 1.00625"
GMR_{1c} = .247"

$$W_s = \left(\frac{1.08 - 1}{1.08}\right)^{1/2} = .272$$

$$F_s = .4$$

$$X = .053 \times 60 \ \log \frac{1.3 \times 1.00625}{.4 \times .539} \quad \text{ohms/mile}$$
$$= .2191 \quad \text{ohms/mile}$$

Considering sheath effect reactance decrement:

Reactance of cable in fiber duct = .162 ohms/mile

$$\text{Sheath effect} = .2794 \ \log \frac{1.00625}{.247} - .162 \quad \text{ohms/mile}$$
$$= .00844 \quad \text{ohms/mile}$$

$$X_{AC} = .2191 - .00844 \quad \text{ohms/mile}$$
$$= .21066 \quad \text{ohms/mile}$$

Reactance of cable in steel conduit = .21066 ohms/mile

XLP and BRNJ Cables: Reactance values for these cables have been computed according to the above formula.

Example:

Cable: 3 conductor copper # 1/o - BRNJ 15 Kv - shielded in 4" steel conduit.

Conductor diameter = .373" a = .187"
Insulation thickness = .297"
GMR_{1c} = .14117"

$$GMD = .373'' + 2(.297'') + .006'' + .03125''$$
$$= 1.004''$$

AC/DC resistance ratio = $R_s = 1.02$

$$W_s = \left(\frac{1.02 - 1}{1.02}\right)^{1/2}$$
$$= .14$$

$$F_s = .394$$

$$X = .053 \times 60 \ \log \frac{1.3 \times 1.004}{.394 \times .373} \quad \text{ohms/mile}$$
$$= .265 \quad \text{Ohms/mile}$$

Reactance of cable in steel conduit = .265

b.2. <u>Single Conductor Cables</u>: Reactance values for these cables have been computed based on the formula:

$$X = .2794 \ K \log \frac{GMD}{GMR_{1c}}$$

Where K = 1.5 — Factor that includes the random spacing of cables in the duct and the magnetic effect of the steel.

Example:

Cable: 3 single conductors 500 MCM - BRNJ 5 Kv - shielded in 4" steel conduit.

Conductor diameter = .855" a = .4275"
Insulation thickness = .172"
GMR_{1c} = .31249"
Core diameter = 1.244"
Outside diameter = 1.47"

$$GMD = (1.2)^{1/3} \times 1.47''$$
$$= 1.5729''$$

$$X_1 = .2794 \times 1.2 \ \log \frac{1.5729}{.31249} \quad \text{ohms/mile}$$
$$= .2358 \quad \text{ohms/mile}$$

Reactance of cable in fiber duct = .236 ohms/mile

$$X = .2794 \times 1.5 \ \log \frac{1.5729}{.31249} \quad \text{ohms/mile}$$
$$= .295 \quad \text{ohms/mile}$$

Reactance of cable in steel conduit = .295 ohms/mile

3. Positive-Negative and Zero Sequence Impedances of Over Head Lines.

Configurations: There are two different configurations; A (horizontal line spacing) and B (vertical line spacing).

Configuration A: Lines a, b, and c in same horizontal 10' cross arm, 5'6" from ground wire at top of pole, 30 ft. above ground. Spacing between lines as follows:

Spacing lines a and b = 2.0 ft. = D_{ab}

Spacing lines b and c = 5.75 ft. = D_{bc}

Spacing lines a and c = 7.75 ft. = D_{ac}

Spacing lines a and g = 6.8 ft. = $(4^2 + 5.5^2)^{1/2} = D_{ag}$

Spacing lines b and g = 5.85 ft. = $(2^2 + 5.5^2)^{1/2} = D_{bg}$

Spacing lines c and g = 6.74 ft. = $(3.9^2 + 5.5^2)^{1/2} = D_{cg}$
g = ground wire

GMD_{abc} = 4.465 ft. = $(2 \times 5.75 \times 7.75)^{1/3}$

Configuration B: Lines a, b, and c on different horizontal planes, all 16" from pole. Ground wire at top of pole 5'6" from line a (highest line horizontal plane). Vertical spacing between lines a, b, and c approximately 2.2325 ft. Average spacing from ground approximately 30 ft.

Spacing lines a and b = 3.5 ft. = D_{ab}

Spacing lines b and c = 3.5 ft. = D_{bc}

Spacing lines a and c = 4.68 ft. = D_{ac}

Spacing lines a and g = 5.59 ft. = $(1.3^2 + 5.5^2)^{1/2} = D_{ag}$

Spacing lines b and g = 7.84 ft. = $(1.69^2 + 7.7325^2)^{1/2} = D_{bg}$

Spacing lines c and g = 10.25 ft. = $(1.69^2 + 10.18^2)^{1/2} = D_{cg}$
g = ground wire

GMD_{abc} = 3.855 ft. = $(3.5 \times 3.5 \times 4.68)^{1/3}$

A. Positive-Negative Sequence Impedances

a) Resistance

$$R_{AC} = R_{DC} \times K_t \times K_s$$

Where R_{AC}, R_{DC}, K_t, and K_s are as defined before in the section for cables.

$$K_s = f(ma)$$

$$ma = .0636\ (^f/R_{DC})^{1/2}$$

K_s is tabulated as a function of ma in Table 5 of "Transmission and Distribution Reference Book" by Westinghouse and in "Underground Systems Reference Book" by EEI.

Values for R_{AC} are available directly in any table of electrical conductor characteristics as in Tables # 1 through # 4, Chapter # 3, "Transmission and Distribution Reference Book" and have been used in this study.

b) Reactance

b.1. Inductive

$$X_1 = X_2 = .2794 \log \frac{GMD}{GMR_{1c}} \quad \text{ohms/mile}$$

$$= .2794 \log \frac{1}{GMR_{1c}} + .2794 \log \frac{GMD}{1}$$

$$= X_a + X_d \quad \text{ohms/mile}$$

Where $X_a = .2794 \log \dfrac{1}{GMR_{1c}}$ ohms/mile

$X_d = .2794 \log \dfrac{GMD}{1}$ ohms/mile

and X_a, X_d are tabulated in Tables # 1 to # 4 and Tables # 6, Chapter # 3 "Transmission and Distribution Reference Book" and have been used for this computation.

The above derivation is based on symmetrically tranposed lines, symmetrical or unsymmetrical spaced conductors. If lines are not transposed and the conductors are unsymmetrically spaced, results are only approximate, but accurate enough for any computation.

b.2. Shunt Capacitive Reactance

$$X_1' = X_2' = .06831 \log \frac{1}{a} + .06831 \log \frac{GMD}{1} \quad \text{megohms.mile}$$

Where a = radius of conductor in ft.

$$= X_a' + X_d' \quad \text{megohms.mile}$$

X_a' and X_d' are tabulated in Tables # 1 to # 4 and Table # 8, Chapter # 3 "Transmission and Distribution Reference Book" and have been used for this computation.

Example:

Line: 3 conductors # 2/o HD bare copper, A configuration.

Radius of conductor = .207"
R_{AC} = .481 ohms/mile at 50° C
X_a = .532 ohms/mile
X_a' = .1205 megohms.mile
GMD = 4.465 ft.
X_d = .1802 ohms/mile
X_d' = .04433 megohms.mile
$X_a + X_d$ = .7132 ohms/mile
$X_1 = X_2$ = .7132 ohms/mile
$X_a' + X_d'$ = .164933 megohms.mile
$X_1' = X_2'$ = .164933 megohms.mile

Line Impedance to positive-negative sequence of 3 conductors # 2/o HD bare copper, A configuration = .481 + j.7132 ohms/mile, - j.164933 megohms.mile.

B. Zero Sequence Impedance

Zero sequence impedance calculations are based on Carson's Fundamental Formulas concerning the nature of earth return currents, which are shown below.

$$Z_g = r_c + .00159f + j.004657f \log_{10} \frac{2160}{GMR_{1c}} \left(\frac{P}{f}\right)^{1/2} \text{ ohms/mile}$$

$$Z_{gm} = .00159f + j.004657f \log_{10} \frac{2160}{D_{ab}} \left(\frac{P}{f}\right)^{1/2} \text{ ohms/mile}$$

Where

Z_g = self-impedance of one conductor with earth return in ohms/mile

Z_{gm} = mutual impedance between two conductors spaced a distance D_{ab} ft. with common earth return in ohms/mile

D_{ab} = distance in feet between conductors a and b (with common earth return)

f = frequency in hertz
p = earth resistivity in ohms per cubic meter
GMR_{1c} = geometric mean radius of conductor in feet

The quantity 2160 $(p/f)^{1/2}$ is defined as D_e or the equivalent depth of the earth return current in feet.

or

$$Z_g = r_c + .0954 + j.27942 \ \log \frac{D_e}{GMR} \ \text{ohms/mile}$$

$$Z_{gm} = .0954 + j.27942 \ \log \frac{D_e}{D_{ab}} \ \text{ohms/mile}$$

a) <u>3 ϕ Circuit Considerations:</u>

For a 3 ϕ circuit with common earth return, a convenient procedure to analyze the system is to replace the 3 line conductors by an equivalent conductor with resistance equal to the 3 line conductors in parallel. Through this equivalent conductor will flow 3 units of current per each unit of current flowing through the line conductors.

These Carson's Formulas applied to a 3 ϕ circuit are

$$Z_{01} = r_c + .2862 + j.8382 \log \frac{D_e}{GMR} \ \text{ohms/mile}$$

$$Z_{om} = .2862 + j.8382 \log \frac{D_e}{GMD_2} \ \text{ohms/mile}$$

Where

Z_{01} = zero sequence self impedance of one 3 ϕ circuit with earth return in ohms/mile

Z_{om} = mutual zero sequence impedance between two 3 ϕ circuits in ohms/mile

r_c = resistance of one line conductor of the 3 ϕ phase system (if all line conductors are equal) in ohms/mile

D_e = equivalent depth of the earth return current in feet, varies accordingly to the nature of the soil

$GMR = (GMR_{1c} \cdot GMD^2)^{1/3}$ in feet

GMD = equivalent spacing between the 3 conductors of one 3 ϕ system in feet

GMD_2 = equivalent spacing between the 6 conductors of two 3 ϕ phase systems in feet

r_e = .2862 = resistance of earth return path in ohms/mile, constant value independently of the nature of the soil

b) Effect of Ground Wires:

The presence of ground wires will provide an additional return path to zero sequence currents in the line and thus will affect the formulation of the zero sequence impedance of the 3 ϕ phase circuit.

If we consider an equivalent conductor to replace the 3 ϕ line, the ground wires will, besides having its own self impedance, have a mutual impedance Z_{om} with the equivalent 3 ϕ phase line conductor; its magnitude given by the Z_{om} formula where GMD will be the equivalent spacing of the 3 line conductor and the ground wires.

If only one ground wire is present, the following formulation will define self and mutual impedances.

$$Z_{og} = 3rg + .2862 + j.8382 \log \frac{D_e}{GMR_{1c}} \quad \text{ohms/mile}$$

Where rg = resistance of ground wire in ohms/mile

GMR_{1c} = geometric mean radius of ground wire

$$Z_{om} = .2862 + j.8382 \log \frac{D_e}{GMD_2} \quad \text{ohms/mile}$$

$$GMD_2 = (D_{ag}.D_{bg}.D_{cg})^{1/3} \quad \text{in feet}$$

The zero sequence impedance of the 3 ϕ circuit with one ground wire will be defined as

$$Z_0 = Z_{01} - \frac{(Z_{om})^2}{Z_{og}}$$

Where Z_{01}, Z_{og}, Z_{om} are the self impedance of the 3 ϕ circuit, the ground wire and the mutual impedance of the line and the ground wire respectively.

Z_o = zero sequence impedance of one 3 ϕ circuit with one ground wire

Example:

Line: 3 conductors $\neq$ 4 HD bare copper, A configuration with one ground wire considered to be equal to the phase conductors (no data was furnished for ground wires)

Radius of Conductor = .102"
r_c = 1.503 ohms/mile at 50°C
GMD = 4.465 ft.
X_a = .609 ohms/mile
GMR_{1c} = .00663 ft.

$$Z_{01} = r_c + r_e + j(X_e + X_a - 2X_d)$$

Where

$$r_e = .2862 \text{ ohms/mile}$$

$$X_e = .8382 \log \frac{D_e}{1} \text{ ohms/mile}$$

Where D_e = 880 ft. for 10 ohms per cubic meter earth resistivity corresponding to sea water.

$$X_e = 2.469 \text{ ohms/mile}$$

$$X_a = .2794 \log \frac{1}{GMR_{1c}} \text{ ohms/mile}$$

$$X_d = .2794 \log GMD$$

$$Z_{01} = 1.503 + .2862 + j[2.469 + .609 - 2(.1802)] \text{ ohms/mile}$$

$$= 1.789 + j\ 2.7176 \text{ ohms/mile}$$

$$Z_{og} = 3r_c + r_e + j(X_e + 3X_a)$$

$$= 3(1.503) + .2862 + j(2.469 + 3 \times .609) \text{ ohms/mile}$$

$$= 4.795 + j\ 4.296 \text{ ohms/mile}$$

$$Z_{om} = r_e + j(X_e - X_{ag} - X_{bg} - X_{cg})$$

Where

$$X_{ag} = .2794 \log D_{ag} \text{ ohms/mile}$$

$$X_{bg} = .2794 \log D_{bg} \text{ ohms/mile}$$

$$X_{cg} = .2794 \log D_{cg} \text{ ohms/mile}$$

and D_{ag}, D_{bg}, and D_{cg} are the respective distances between the ground wire and conductors a, b, and c in feet.

$$Z_{om} = .2862 + j(2.469 - .2317 - .2140 - .2317) \text{ ohms/mile}$$

$$= .2862 + j\ 1.7917 \text{ ohms/mile}$$

There

$$Z_o = Z_{01} - \frac{(Z_{om})^2}{Z_{og}}$$

$$= 1.789 + j\,2.7176 - \frac{(.2862 + j\,1.7916)^2}{4.795 + j\,4.296} \quad \text{ohms/mile}$$

$$Z_o = 2.0446888 + j\,2.274953 \quad \text{ohms/mile}$$

Zero sequence impedance formed of 3 conductors # 4 HD bare copper with one ground wire of same characteristics, A configuration is:

$$2.04469 + j\,2.27495 \quad \text{ohms/mile}$$

Zero Sequence Shunt Capacitive Reactance:

Calculations of zero sequence shunt capacitive reactance of 3 ϕ circuits with earth return will be influenced by the presence of ground wires in a manner similar to the inductive reactance calculations as will be indicated by the following formulas:

Zero sequence shunt capacitive reactance (X'_{01}) of one 3 ϕ line with earth return (no ground wires)

$$X'_{01} = X'_a + X'_e - 2X'_D \quad \text{megohms.mile}$$

Where

$$X'_a = .0683 \log \frac{1}{a} \qquad a = \text{radius of conductor in feet}$$

$$X'_e = .205 \log 2h \qquad h = \text{mean height of line conductors above ground in feet}$$

$$X'_d = .0683 \log GMD$$

Zero sequence shunt capacitive reactance (X'_{og}) of one ground wire with earth return

$$X'_{og} = 3X'_g + X'_{eg} \quad \text{megohms.mile}$$

Where

$$X'_g = .0683 \log \frac{1}{a'} \qquad a' = \text{radius of ground wire in feet}$$

$$X'_{eg} = .205 \log 2h' \qquad h' = \text{height of ground wire above ground in feet}$$

Zero sequence mutual capacitive reactance (X'_{om}) between one 3 ϕ line and one ground wire with earth return

$$X'_{om} = X'_e - X'_{dag} - X'_{dbg} - X'_{dcg} \quad \text{megohms.mile}$$

Where

$$X'_{dag} = .0683 \log D_{ag}$$

$$X'_{dbg} = .0683 \log D_{bg}$$

$$X'_{dcg} = .0683 \log D_{cg}$$

Zero sequence shunt capacitive reactance (X'_o) of one 3 ϕ circuit with one ground wire and earth return

$$X'_o = X'_{01} - \frac{(X'_{om})^2}{X'_{og}} \quad \text{megohms.mile}$$

Zero sequence shunt capacitive reactance $(X_c^{'})$ of one 3 ϕ circuit with one ground wire and earth return

$$X_o^{'} = X_{01}^{'} - \frac{(X_{om}^{'})^2}{X_{og}^{'}} \quad \text{megohms.mile}$$

Example:

Line: 3 conductors # 4 HD bare copper with one ground wire equal to line conductor with earth return, A configuration.

Radius of conductor = .102"

$X_a^{'} = .1415$ megohms.mile

GMD = 4.465 ft.

$X_g^{'} = X_a^{'} = .1415$ megohms.mile

h = 30 ft.

$h^{'} = 35.5$ ft.

$X_e^{'} = .364$ megohms.mile

$X_{eg}^{'} = .3795$ megohms.mile

$X_d^{'} = .0443333$ megohms.mile

$X_{dag}^{'} = .0567$ megohms.mile

$X_{dbg}^{'} = .0523$ megohms.mile

$X_{dcg}^{'} = .0567$ megohms.mile

$X_{01}^{'} = -j.1415 - j.364 - 2j(.0443333)$ megohms.mile

$= -j.4166334$ megohms.mile

$X_{og}^{'} = 3(-j.1415) - j.3795$ megohms.mile

$= -j.8040$ megohms.mile

$X_{om}^{'} = -j.364 - [-j.0567 - j.0523 - j.0567]$ megohms.mile

$= -j.1983$ megohms.mile

$X_o^{'} = -j.4166334 - \dfrac{(-j.1983)^2}{-j.8040}$ megohms.mile

$= -j.3667631$ megohsm.mile

Zero sequence shunt capacitive reactance of 3 conductors # 4 HD bare copper with equal ground wire with earth return, A configuration = -j.3667631 megohms.mile.

4. Zero Sequence Impedance of 3 ϕ Power Cables

A. General

Zero sequence impedance calculations of 3 ϕ power cables are based on Carson's Fundamental Formulas introduced in the Aerial Lines Section which applied to a 3 ϕ system yields the following equations.

$$Z_{01} = r_c + r_e + j.8382 \log \frac{D_e}{GMR} \text{ ohms/mile}$$

$$Z_{om} = r_e + j.8382 \log \frac{D_e}{GMD_2} \text{ ohms/mile}$$

Where

Z_{01} = zero sequence self impedance of one 3 ϕ circuit with earth return

r_c = resistance of one line conductor of the 3 ϕ system in ohms/mile (if all conductors are equal)

$GMR = (GMR_{1c} \cdot GMD^2)^{1/3}$ in feet

GMD = equivalent spacing in feet between the 3 line conductor of one 3 ϕ system

GMR_{1c} = geometric mean radius of one line conductor in feet

D_e = equivalent depth of earth return current in feet. In this study, D_e = 880 ft. corresponding to an earth resistivity of 10 ohms.meter cube (sea water)

Z_{om} = mutual zero sequence impedance between two 3 ϕ circuits

GMD_2 = spacing between the equivalent conductors of two 3 ϕ systems or the equivalent spacing between the 6 conductors of two 3 ϕ systems

Several formulations are required to model the behavior of different types of cables under different installation conditions. The following cases are considered for grounded 3 ϕ systems:

a) 3 conductor sheathed cable in steel conduit with earth return

a') 3 conductor sheathed cable in fiber duct with earth return

b) 3 conductor non-sheathed cable in steel conduit with earth return

b') 3 conductor non-sheathed cable in fiber duct with earth return

c) 3 conductor sheathed cable installed aerially suspended from a messenger with one ground wire at top with earth return

c') 3 conductor sheathed cable installed aerially suspended from a messenger with earth return

d) 3 single conductor non-sheathed cables in steel conduit with earth return

d') 3 single conductor non-sheathed cables in fiber duct with earth return

e) 3 single conductor non-sheathed cables aerially suspended from a messenger with one ground wire at top with earth return

e') 3 single conductor non-sheathed cables aerially suspended from a messenger with earth return

f) 3 single conductors + one grounded neutral conductor in steel pipe with earth return

f') 3 single conductos + one grounded neutral conductor in fiber duct with earth return

B. Case a': 3 conductor sheathed cable in fiber duct with earth return (typical for PILCNJ cables in fiber duct or directly buried in earth)

In this case, there are 2 possible different return paths for zero sequence currents: sheath and earth with interrelated mutual coupling which, due to the definition of Carson's Formulas, cannot be successfully decoupled as independent terms, but must be considered as acting jointly together. The figure shown below depicts current flow in these paths together with the voltage drop expressions (the figure is not an impedance diagram).

If we replace the 3 conductors of 3 ϕ cable by one equivalent conductor with a resistance equal to the resistance of one conductor and with an equivalent geometric mean radius GMR = $(GMR_{1c} \cdot GMD^2)^{1/3}$, the self impedance of the cable conductors can be formulated as

$$Z_e = r_c + r_e + j.8382 \ \log \frac{D_e \times 12}{GMR}$$

Similarly, we can define the self-impedance of the sheath as:

$$Z_s = 3r_s + r_e + j.8382 \ \frac{D_e \times 12}{a_{sH}}$$

Where

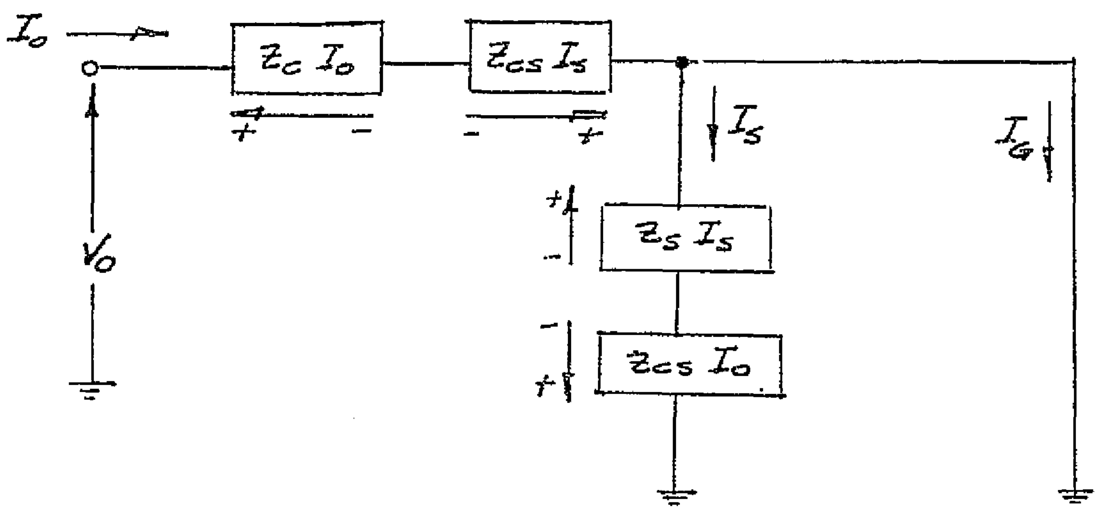
r_s = resistance of sheath in ohms/mile
a_{sH} = radius of sheath in inches
GMR = $(GMR_{1c} * GMD^2)^{1/3}$ in inches

And the mutual coupling between sheath and the equivalent conductor as:

$$Z_{cs} = r_e + j.8382 \ \log \frac{D_e * 12}{D_{cs}}$$

Where

D_{cs} = equivalent spacing between conductors and sheath in inches
$= a_{sH}$ (approximate) inches



Applying Kirchoff's Equations:

$$I_o = I_s + I_G$$

$$V_o = I_o Z_c - I_s Z_{cs} + I_s Z_s - I_o Z_{cs}$$

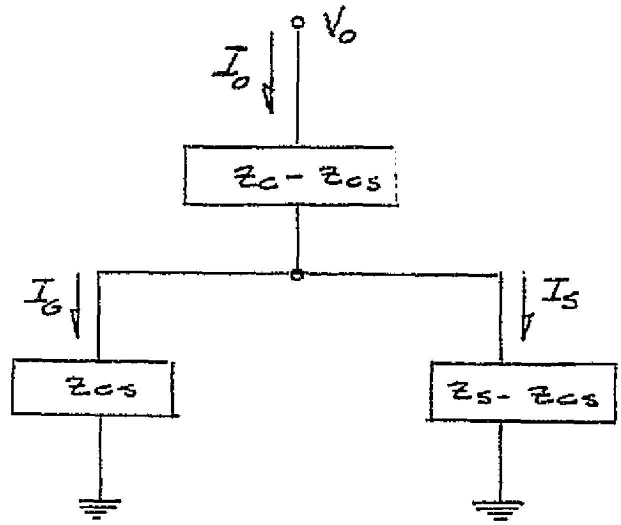
1) $$= I_o (Z_c - Z_{cs}) + I_s (Z_s - Z_{cs})$$

$$0 = I_s Z_s - I_o Z_{cs}$$

But
$$I_o = I_s + I_G$$
Or

2) $$0 = I_s (Z_s - Z_{cs}) - I_G Z_{cs}$$

and the equations 1) and 2) defines the model.



Solving fo I_s and substituting in 1)

$$I_s = I_o \frac{Z_{cs}}{Z_s}$$

$$V_o = I_o\ (Z_c - Z_{cs}) + I_o\ (Z_s - Z_{cs}) \frac{Z_{cs}}{Z_s}$$

$$V_o = \frac{I_o}{Z_s}\ [Z_c Z_s - Z_s Z_{cs} + Z_s Z_{cs} - Z_{cs} \cdot Z_{cs}]$$

$$V_o = I_o\ [Z_c - \frac{(Z_{cs})^2}{Z_s}]$$

And

$$Z_o = \frac{V_o}{I_o} = Z_c - \frac{(Z_{cs})^2}{Z_s}$$

And the zero sequence impedance of one conductor sheathed cable in fiber duct with earth return is given by

$$Z_o = Z_c - \frac{(Z_{cs})^2}{Z_s}$$

This is a theoretical formulation that takes into consideration the existence of two possible return paths for the fault current. Several fault and grounding conditions will affect the impedance of the return path:

1) The resistance of the sheath to ground connection is not low enough that could be disregarded or the sheath is open to ground.

Under this condition, the return path impedance will increase its value approaching a ground return only given by:

$$Z_o = Z_c = r_c + r_e + j.8382 \ \log \frac{D_e * 12}{GMR} \ \text{ohms/mile}$$

2) The initial fault current returns through the sheath and either is cleared before it can develop to the earth or is prevented by the cable jacket.

Under this condition, the only return path available is through the sheath and its value is given by the equation:

$$Z_o = Z_c + Z_s - 2Z_{cs}$$

$$= r_c + 3r_s + j.8382 \ \log \frac{a_{sH}}{GMR} \ \text{ohms/mile}$$

3) The initial fault current returns through the sheath and after few cycles develops to the earth with an impedance given by:

$$Z_o = Z_c - \frac{(Z_{cs})^2}{Z_s}$$

Several tests conducted by an utility company indicate that this is the most likely condition to occur and it has been considered as such for our calculations.

Comparison values for a 3 conductor 500 MCM - CS - PILCNJ 15 Kv - shielded in 4" fiber duct are as follows:

Z_o = 3.60 ohms/mile for earth return only
= .435 + j3.5586 ohms/mile

Z_o = 1.998 ohms/mile for sheath return only
= 1.979 + j.272 ohms/mile

Z_o = 1.81 ohms/mile for sheath + earth return
= 1.515592 + j.99027 ohms/mile

C. <u>Case a)</u> 3 conductor sheathed cable in steel conduit with earth return (typical for PILCNJ Cables in steel conduit)

In this case, there are 3 possible return paths for zero sequence currents: sheath, conduit, and earth. The behavior of the conduit impedance is a random function of the magnitude of current through the pipe and the pipe diameter.

If Z_p is defined as the pipe self-impedance and Z_{cp} is the mutual impedance between the cable conductors and the pipe, a derivation by J' H' Neher, published in IEEE Transactions on Power Apparatus and Systems - August 1964, pg. 797 to 804 provide a view of the nature of the problem. An excerpt of it follows:

Evaluation of $Z_p - Z_{cp} = 3(R_p + jX_p)$

(From a paper by J' H' Neher published in IEEE August 1964.)

If J_x is the current density in the pipe at a radius $r_p + x$ (x = fraction of pipe thickness), then the net current flowing in the pipe inside a circle of radius $r_p + x$ is:

$$I_x = \int_0^x 2\pi (r_p + x)\, J_x dx + (I_s + I_G - I_o)$$

$$I_x \simeq 2\pi\, r_p \int_0^x J_x dx + (I_s + I_G - I_o) \quad \text{for } x \ll r_p$$

$$I_x = \pi D_p \int_0^x J_x dx + (I_s + I_G - I_o)$$

D_p = pipe diameter

Then

$$H_x = \frac{I_x}{(D_p + 2x)} \approx \frac{I_x}{\pi D_p}$$

$$H_x = \int_0^x J_x dx + \frac{I_s + I_G - I_o}{D_p}$$

Then

$$J_x = \frac{dH_x}{d_x}$$

The induced emf is $\frac{d\phi}{dt} = \mu' \, dx \, \frac{dH_x}{dt} \times 10^{-8}$ volts/inch which must equal the voltage drop:

$$\mu' dx \; \frac{dH_x}{dt} \times 10^{-8} = \rho \frac{dJ_x}{dx} \; dx \; . \; 10^{-6} \quad \text{volts/inch}$$

$$\frac{dJ_x}{dt} = \frac{d^2H_x}{dxdt} \qquad \text{and} \qquad \frac{dH_x}{dt} = \left(\frac{\rho}{\mu'}\right) \times 10^2 \; \frac{dJ_x}{dx}$$

Or

$$\frac{d^2H_x}{dxdt} = 10^2\left(\frac{\rho}{\mu'}\right)\frac{d^2J_x}{dx^2}$$

Assuming a sinusoidal variation $J_x = J_{xm}\, e^{jwt}$

$$\frac{dJ_x}{dx} = jwJ_x \longrightarrow \frac{d^2J_x}{dx^2} = jw\,\frac{\mu'}{\rho}\,J_x \times 10^{-2}$$

Or

$$J_x = J_o e^{-cx} e^{-jcx}$$

Then the total current in the pipe is:

$$I_p = \pi D_p \int_o^{tp} J_x dx = \frac{J_o(1-j)}{2c}\left[1 - e^{-ctp(1+j)}\right] \pi D_p$$

$$V_p = -\int_o^{tp} \rho \frac{dJ_x}{dx}\, dx = 12\,\rho\, J_o \left[1 - e^{-ctp\,(1+j)}\right]$$

$$Z_p = \frac{V_p}{I_p} = \frac{\rho c\,(1+j)}{\pi D_p} = \frac{9.4\,(1+j)\sqrt{\mu\rho}}{D_p} \quad \text{micro-ohms/foot}$$

Then

$$Z_p D_p = K\sqrt{\mu}$$

The values of μ and K are random and depend of the value of I_p.

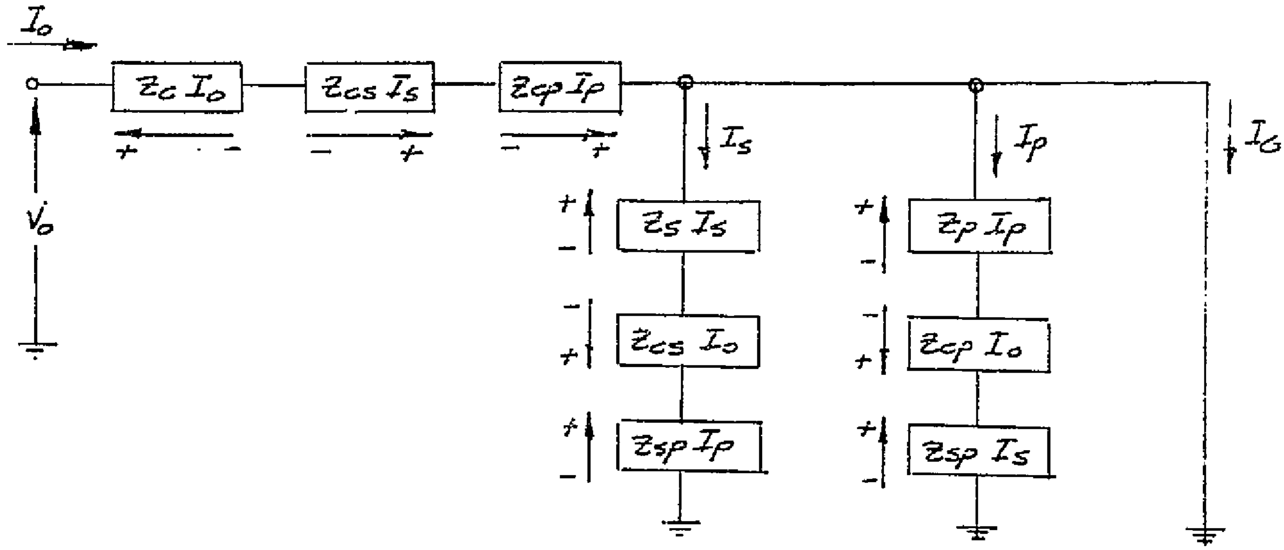
From average data for $500\text{ A} \leq I_p \leq 7400\text{ A}$

$R_p = 29.9\sqrt{\mu}/D_p$ micro-ohms/foot D_p in inches

$X_p = 18.1\sqrt{\mu}/D_p$ micro-ohms/foot

$\sqrt{\mu} = 15.36$

For this case the zero sequence system can be represented by the current flow diagram:



Applying Kirchoff's Equations:

1) $I_o = I_s + I_p + I_G$

2) $V_o = I_o (Z_c - Z_{cp}) + I_s (Z_{sp} - Z_{cs}) + I_p (Z_p - Z_{cp})$

3) $V_o = I_o (Z_c - Z_{cs}) + I_s (Z_s - Z_{cs}) + I_p (Z_{sp} - Z_{cp})$

4) $0 = -I_o Z_{cs} + Z_s I_s + Z_{sp} I_p$

$$= I_s (Z_s - Z_{cs}) + I_p (Z_{sp} - Z_{cs}) - I_G Z_{cs}$$

And the redundant equations

$$0 = I_o (Z_{cs} - Z_{cp}) + I_s (Z_{sp} - Z_s) + I_p (Z_p - Z_{sp})$$

$$0 = I_s (Z_{sp} - Z_{cp}) + I_p (Z_p - Z_{cp}) - I_G Z_{cp}$$

Or in Matrix Form

$$\begin{vmatrix} V_o \\ V_o \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} Z_c - Z_{cp} & Z_{sp} - Z_{cs} & Z_p - Z_{cp} & 0 \\ Z_c - Z_{cs} & Z_s - Z_{cs} & Z_{sp} - Z_{cp} & 0 \\ -Z_{cs} & Z_s & Z_{sp} & 0 \\ -1 & 1 & 1 & 1 \end{vmatrix} \begin{vmatrix} I_o \\ I_s \\ I_p \\ I_G \end{vmatrix}$$

Solving for I_o by Cramer's Rule and using minors

$$I_o = \frac{\det \begin{vmatrix} V_o & Z_{sp} - Z_{cs} & Z_p - Z_{cp} \\ V_o & Z_s - Z_{cs} & Z_{sp} - Z_{cp} \\ 0 & Z_s & Z_{sp} \\ 0 & 1 & 1 \end{vmatrix}}{\det \begin{vmatrix} Z_c - Z_{cp} & Z_{sp} - Z_{cs} & Z_p - Z_{cp} \\ Z_c - Z_{cs} & Z_s - Z_{cs} & Z_{sp} - Z_{cp} \\ -Z_{cs} & Z_s & Z_{sp} \end{vmatrix}}$$

$$I_o = \frac{V_o\,[Z_s\,(Z_p - Z_{sp}) + Z_{sp}(Z_s - Z_{sp})]}{\begin{array}{l} Z_s[(Z_c - Z_{cs})(Z_p - Z_{cp}) + (Zc - Z_{cp})(Z_{cp} - Z_{sp})] \\ + Z_{sp}\,[(Z_c - Z_{cp})(Z_s - Z_{cs}) + (Z_c - Z_{cs})\,(Z_{cs} - Z_{sp})] \\ + Z_{cs}\,[(Z_p - Z_{cp})\,(Z_s - Z_{cs}) + (Z_{cs} - Z_{sp})\,(Z_{sp} - Z_{cp})] \end{array}}$$

And

$$\frac{V_o}{I_o} = Z_o \quad \frac{Z_s\,[(Z_c - Z_{cs})(Z_p - Z_{cp}) + (Z_c - Z_{cp})(Z_{cp} - Z_{sp})]}{Z_s\,(Z_p - Z_{sp}) + Z_{sp}\,(Z_s - Z_{sp})}$$

$$+ \frac{Z_{sp}\,[(Z_c - Z_{cp})(Z_s - Z_{cs}) + (Z_c - Z_{cs})(Z_{cs} - Z_{sp})]}{Z_s\,(Z_p - Z_{sp}) + Z_{sp}\,(Z_s - Z_{sp})}$$

$$+ \frac{Z_{cs}\,[(Z_p - Z_{cp})(Z_s - Z_{cs}) + (Z_{cs} - Z_{sp})(Z_{sp} - Z_{cp})}{Z_s\,(Z_p - Z_{sp}) + Z_{sp}\,(Z_s - Z_{sp})}$$

Where:

Z_c, Z_s, Z_p are the self impedances corresponding to the cable conductors, the sheath, and the pipe. Z_{cp}, Z_{cs}, and Z_{sp} are the mutual impedances between conductors and pipe, conductors and sheath, and sheath and pipe.

Parameters definition:

$$Z_c = r_c + r_e + j.8382 \log \frac{D_e * 12}{GMR} \quad \text{ohms/mile}$$

$$GMR = (GMR_{1c} * GMD^2)^{1/3} \quad \text{inches}$$

$$Z_s = 3r_s + r_e + j.8382 \log \frac{D_e * 12}{a_{sH}} \quad \text{ohms/mile}$$

a_{sH} = radius of sheath in inches

$$Z_p - Z_{cp} = 3R_p + j\,3X_p$$

$$R_p = 15.36 * 29.9 * 5.28/(D_p * 1000) \quad \text{ohms/mile}$$

D_p = pipe diameter in inches

$$X_p = 15.36 * 18.1 * 5.28/(D_p * 1000) \quad \text{ohms/mile}$$

$$Z_{cp} = r_e + j.8382 \log \frac{D_e * 12}{a_p}$$

a_p = radius of pipe in inches

$$Z_p = 3R_p + r_e + j(3X_p + .8382 \log (D_e * 12/a_p) \quad \text{ohms/mile}$$

$$Z_{cs} = r_e + j.8382 \log \frac{D_e * 12}{a_{sH}} \quad \text{ohms/mile}$$

$$Z_{sp} = r_e + j.8382 \log \frac{D_e * 12}{a_p - a_{sH}} \quad \text{ohms/mile}$$

$$Z_c - Z_{cp} = r_c + j.8382 \log \frac{a_p}{GMR} \quad \text{ohms/mile}$$

$$Z_c - Z_{cs} = r_c + j.8382 \log \frac{a_{sH}}{GMR} \quad \text{ohms/mile}$$

$$Z_s - Z_{cs} = 3r_s + j0.$$

Z_{cp} approx. $= Z_{sp}$

Z_{cs} approx. = Z_{sp} approx. = Z_{cp}

Under this approximation a model was developed with a solution given by:

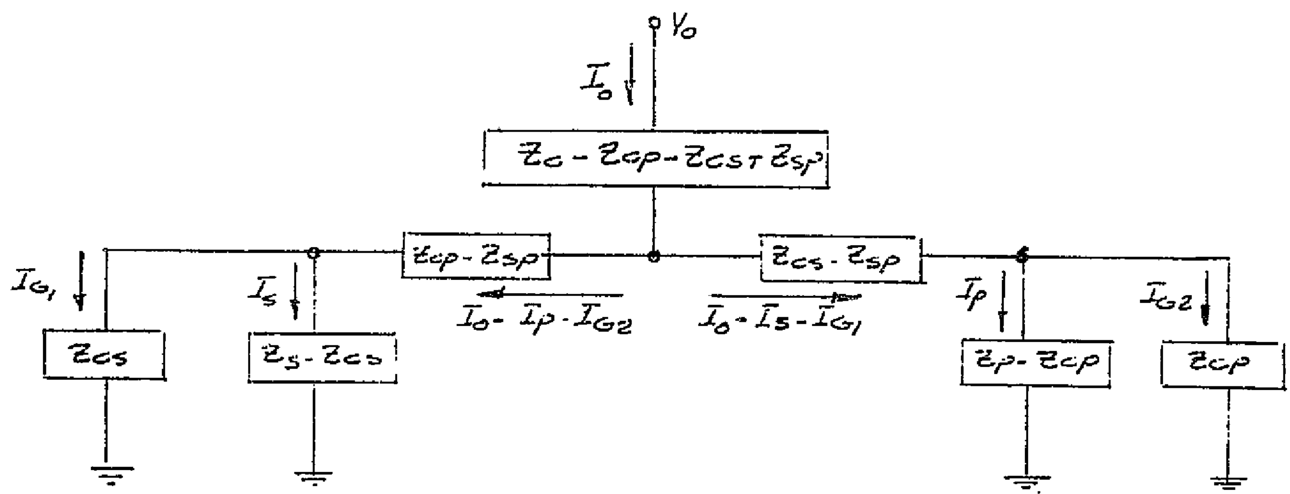
$$Z_o = Z_c - Z_{cp} - (Z_{cs} - Z_{sp}) + \frac{Z_1}{Z_2}$$

Where

$$Z_1 = [Z_s (Z_{cp} - Z_{sp}) + Z_{cs} (Z_s - Z_{cs})][Z_p (Z_{cs} - Z_{sp}) + Z_{cp} (Z_p - Z_{cp})]$$

$$Z_2 = Z_s Z_p (Z_{cs} + Z_{cp} - 2Z_{sp}) + Z_p Z_{cs} (Z_c - Z_{cs}) + Z_s Z_{cp} (Z_p - Z_{cp})$$

The approximated model diagram is as follows:



Results using the two equations of Z_o for sheathed 3 conductor 500 MCM - PILCNJ - 15 Kv cable are as follows:

Using mathematical solution Z_o = .90097 + j.88789 ohms/mile
= 1.27 ohms/mile

Using approximated model Z_o = .7393 + j.99824 ohms/mile
= 1.25 ohms/mile

% Difference = 1.6% in magnitude

The approximated model will evolve into the following cases:

1. Sheathed Cable in metallic conduit without earth return:

System Equations:

1) $V_o = I_o\ (Z_c - Z_{cp}) + I_s\ (Z_{sp} - Z_{cs}) + I_p\ (Z_p - Z_{cp})$

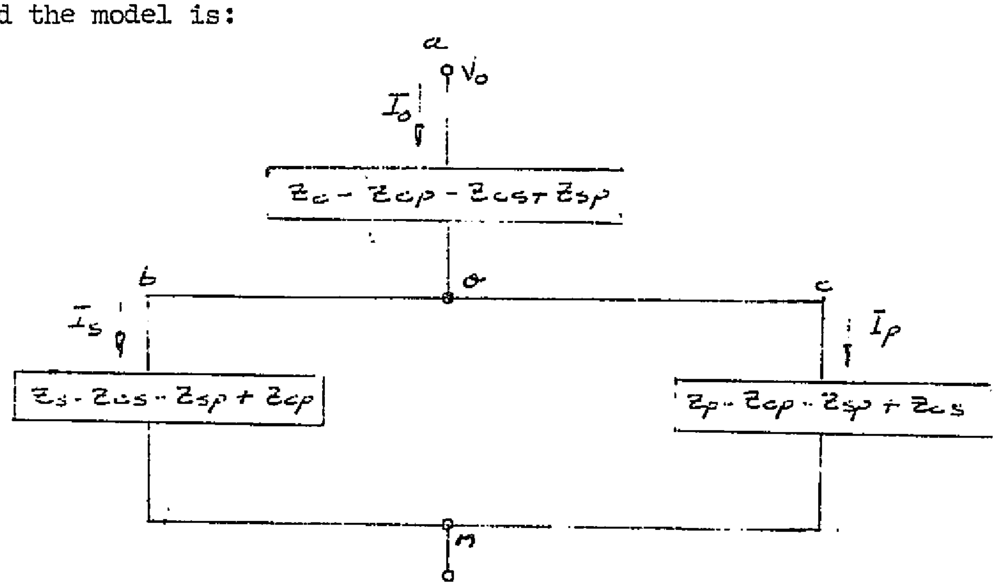
2) $0 = I_o\ (Z_{cs} - Z_{cp}) + I_s\ (Z_{sp} - Z_s) + I_p\ (Z_p - Z_{sp})$

3) $0 = I_o - I_s - I_p$

With Solution:

$$Z_o = (Z_c - Z_{cp}) + (Z_p - Z_{cp}) - \frac{(Z_p - Z_{cp} + Z_{cs} - Z_{sp})^2}{Z_s - Z_{sp} + Z_p - Z_{sp}}$$

And the model is:



Which fulfils the system equations by substituting $I_s = I_o - I_p$ in 1) and substituting $I_o = I_p + I_s$ in 2) and moving thru points a, o, c, n, and thru points cnbo.

This model evolves from the original opening the I_{G_1} and I_{G_2} branches for the earth return path.

2. Sheathed Cable in fiber duct with earth return:

System Equations:

$$V_o = I_o\,(Z_c - Z_{cs}) + I_s\,(Z_s - Z_{cs})$$

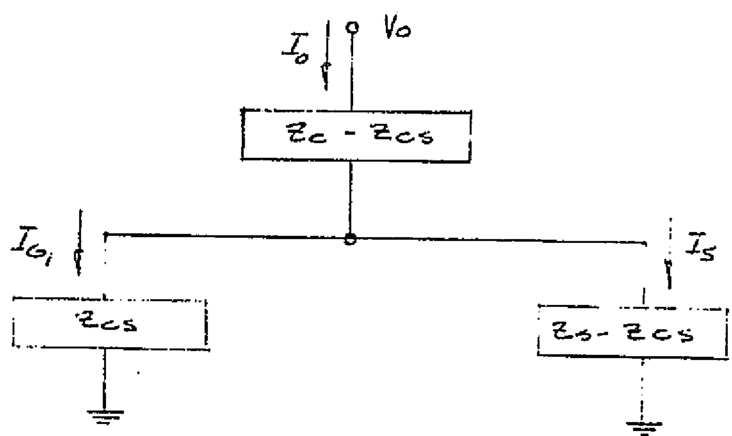
$$0 = I_s\,(Z_s - Z_{cs}) - I_{G_1}\,Z_{cs}$$

$$I_o = I_s + I_{G_1}$$

With Solution:

$$Z_o = Z_c - \frac{(Z_{cs})^2}{Z_s}$$

And the model:



#3. Non-sheathed Cable in metallic pipe with earth return:

System Equations:

$$V_o = I_o\,(Z_c - Z_{cp}) + I_p\,(Z_p - Z_{cp})$$

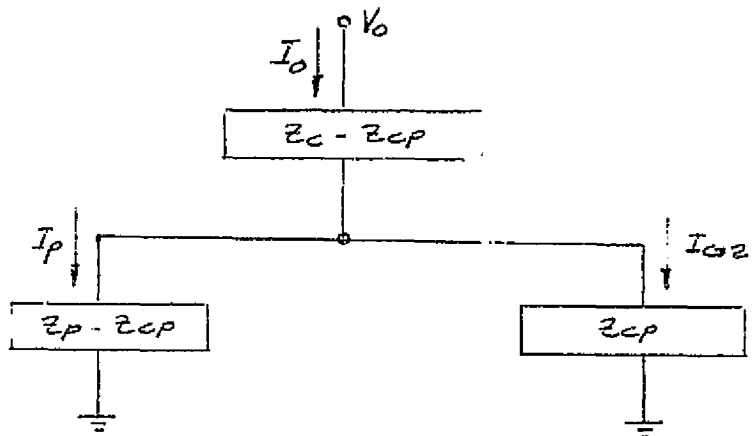
$$0 = I_p\,(Z_p - Z_{cp}) - I_{G_2}\,Z_{cp}$$

$$I_o = I_p + I_{G_2}$$

With Solution:

$$Z_o = Z_c - \frac{(Z_{cp})^2}{Z_p}$$

And the model is:



D. Case b: 3 conductor non-sheathed cable in steel conduit with earth return.

This is the case of the BRNJ 15 Kv and 5 Kv and XLP 15 Kv and 23 Kv cables installed in conduit and has been formulated in # 3 above.

$$Z_o = Z_c - \frac{(Z_{cp})^2}{Z_p} \text{ ohms/mile}$$

Where

$$Z_c = r_c + r_e + j.8382 \log \frac{D_e * 12}{GMR} \text{ ohms/mile}$$

$$Z_p - Z_{cp} = 3R_p + j3X_p \text{ ohms/mile}$$

$$R_p = 15.36 * 29.9 * 5.28/(D_p * 1000) \text{ ohms/mile}$$

$$X_p = 15.36 * 18.1 * 5.28/(D_p * 1000) \text{ ohms/mile}$$

$$D_p = \text{pipe diameter in inches} = 2a_p$$

$$Z_{cp} = r_e + j.8382 \log \frac{D_e * 12}{a_p} \text{ ohms/mile}$$

$$Z_p = 3R_p + r_e + j(3X_p + .8382 \log \frac{D_e * 12}{a_p}) \text{ ohms/mile}$$

E. Case b': 3 conductor non-sheathed cable in fiber duct with earth return(typical case for BRNJ and XLP 5 Kv, 15 Kv, and 23 Kv installed in fiber duct or directly buried in earth).

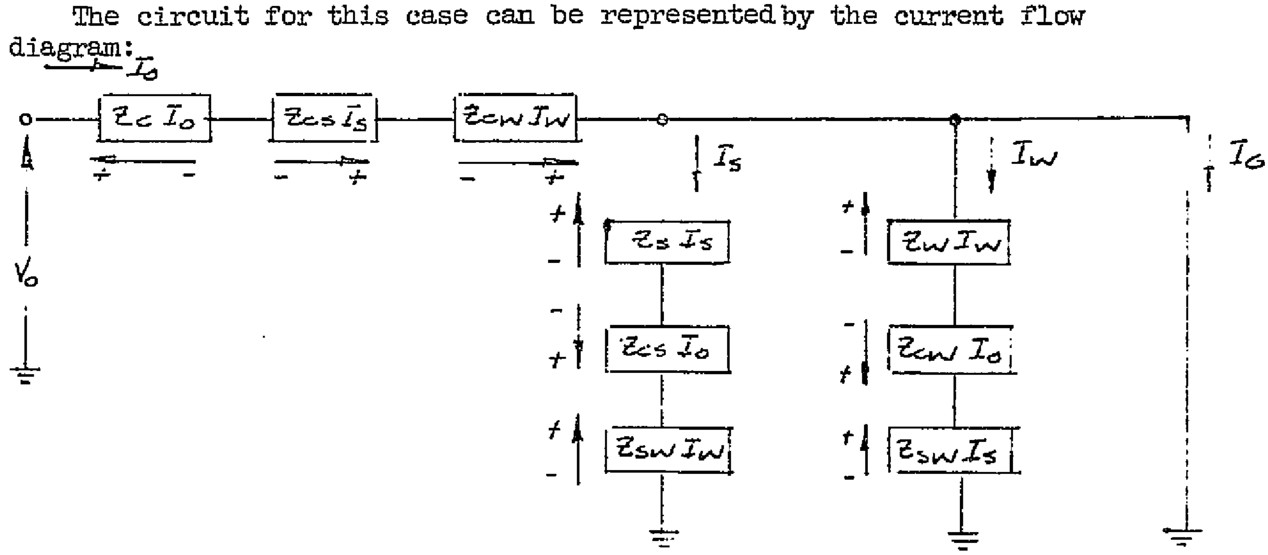
For this case, as the earth is the only return path for zero sequence currents:

$$Z_o = r_c + r_e + j.8382 \ \log \frac{D_e * 12}{GMR} \quad \text{ohms/mile}$$

F. Case c: 3 conductor sheathed cable installed aerially suspended from a messenger with one ground wire at top with earth return (typical for PIAC aerial cables).

In this case, there are 4 possible return paths for zero sequence currents: sheath, messenger, ground wire, and earth. These 4 possible return paths can be reduced to only 3 because the messenger and ground wire can be considered as an equivalent ground system and apply the equations for n ground wires in aerial lines.

The circuit for this case can be represented by the current flow diagram:



Applying Kirchoff's Equations:

1) $I_o = I_s + I_w + I_G$

2) $V_o = I_o (Z_c - Z_{cw}) + I_s (Z_{sw} - Z_{cs}) + I_w (Z_w - Z_{cw})$

3) $V_o = I_o (Z_c - Z_{cs}) + I_s (Z_s - Z_{cs}) + I_w (Z_{sw} - Z_{cw})$

4) $0 = -I_o Z_{cs} + Z_s I_s + Z_{sw} I_w$

Which are the same equations that define "Case a" substituting the pipe (p) by the ground wire (w). Thus, the solution is:

$$Z_o = Z_s \frac{[(Z_c - Z_{cs})(Z_w - Z_{cw}) + (Z_c - Z_{cw})(Z_{cw} - Z_{sw})]}{Z_s (Z_w - Z_{sw}) + Z_{sw} (Z_s - Z_{sw})} \quad +$$

$$+ Z_{sw} \frac{[(Z_c - Z_{cw})(Z_s - Z_{cs}) + (Z_c - Z_{cs})(Z_{cs} - Z_{sw})]}{Z_s (Z_w - Z_{sw}) + Z_{sw} (Z_s - Z_{sw})}$$

$$+ Z_{cs} \frac{[(Z_w - Z_{cw})(Z_s - Z_{cs}) + (Z_{cs} - Z_{sw})(Z_{sw} - Z_{cw})]}{Z_s (Z_w - Z_{sw}) + Z_{sw} (Z_s - Z_{sw})}$$

Parameters Definition:

$$Z_c = r_c + r_e + j.8382 \log \frac{D_e * 12}{GMR} \text{ ohms/mile}$$

$$GMR = (GMR_{1c} * GMD^2)^{1/3} \text{ in inches}$$

$$Z_s = 3r_s + r_e + j.8382 \log \frac{D_e * 12}{a_{sH}} \text{ ohms/mile}$$

a_{sH} = radius of sheath in inches

$$Z_w = 3r_{weg} + r_e + j.8382 \log \frac{D_e * 12}{GMR_w}$$

r_{weg} = equivalent resistance in ohms/mile of the parallel combination of messenger and ground wires

$$Z_{cs} = r_e + j.8382 \log \frac{D_e * 12}{a_{sH}} \text{ ohms/mile}$$

$$Z_{cw} = r_e + j.8382 \log \frac{D_e * 12}{D_{cw}} \text{ ohms/mile}$$

$$Z_{sw} = r_e + j.8382 \log \frac{D_e * 12}{D_{sw}} \text{ ohms/mile}$$

Where

$$GMR_w = (.779 * a_w * .779 * a_m * H^2)^{1/4} \text{ inches}$$

a_m = radius of messenger wire in inches

a_w = radius of ground wire in inches

H = spacing between messenger and ground wire in inches

D_{cw} = equivalent spacing between the cable conductors and the messenger-ground wires assembly

$$D_{cw} = (d_{c_m} * d_{c_w})^{1/2} \text{ inches}$$

Where

d_{cm} = geometrical mean distance from the aerial cable conductors to the messenger wire

d_{cw} = geometrical mean distance from the aerial cable conductors to the ground wire in inches

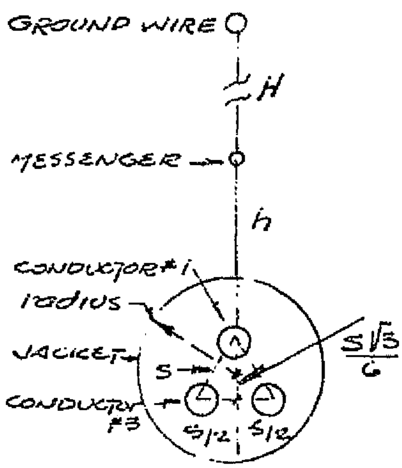
$$D_{sw} = (d_{sm} * d_{sw})^{1/2} \text{ inches}$$

Where

d_{sm} = geometrical mean distance from the aerial cable sheath to the messenger wire

d_{sw} = geometrical mean distance from the aerial cable to the ground wire

<u>Evaluation of d_{cm} and d_{cw}</u>



$$d_{cm} = (d_{cm_1} * d_{cm_2} * d_{cm_3})^{1/3}$$

But, in general

$$d_{cm_2} = d_{cm_3}$$

$$d_{cm} = [d_{cm_1} * (d_{cm_2})^2]^{1/3}$$

$$d_{cm_1} = \frac{OD}{2} + h - \frac{\sqrt{3}}{3} s$$

$$d_{cm_2} = [(h + \frac{OD}{2} + \frac{\sqrt{3}}{6} s)^2 + \frac{s^2}{4}]^{1/2}$$

OD = cable outside diameter

For h approx. equal to $\frac{OD}{2}$

$$d_{cm_1} = OD - s\frac{\sqrt{3}}{3}$$

$$d_{cw_2} = [(OD + s\frac{\sqrt{3}}{6})^2 + \frac{s^2}{4}]^{1/2}$$

$$d_{cm} = \left\{(OD - s\frac{\sqrt{3}}{3}) [\frac{s^2}{4} + (OD + s\frac{\sqrt{3}}{6})^2]\right\}^{1/3} \text{ inches}$$

If H = spacing between messenger and ground wires in inches

$$d_{cw} = \left\{ (H + OD - s\tfrac{\sqrt{3}}{3}) \left[\tfrac{s^2}{4} + (H + OD + s\tfrac{\sqrt{3}}{6})^2 \right] \right\}^{1/3} \text{ inches}$$

In our installation $H = 5'6'' = 66''$

Thus

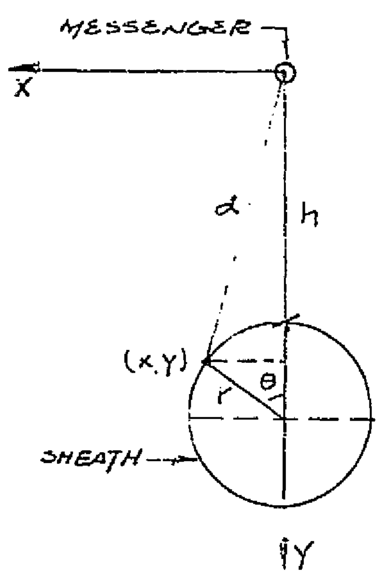
$$d_{cw} = (66 + OD - s\tfrac{\sqrt{3}}{3}) \left[\tfrac{s^2}{4} + (66 + OD + s\tfrac{\sqrt{3}}{6})^2 \right]^{1/3} \text{ inches}$$

Evaluation of D_{cw}

$$D_{cw} = (d_{cm} * d_{cw})^{1/2}$$

$$= \left\{ (OD - s\tfrac{\sqrt{3}}{3}) \left[\tfrac{s^2}{4} + (OD + s\tfrac{\sqrt{3}}{6})^2 \right] (66 + OD - s\tfrac{\sqrt{3}}{3}) \left[\tfrac{s^2}{4} + (66 + OD + s\tfrac{\sqrt{3}}{6})^2 \right] \right\}^{1/6} \text{ inches}$$

Evaluation of d_{sm} and d_{sw}



$$d^2 = x^2 + y^2 = d_{sm}$$

$$x = r \sin\theta$$

$$y = h + r(1 - \cos\theta)$$

$$d^2 = (r \sin\theta)^2 + [h + r(1 - \cos\theta)]^2$$

$$d^2_{avg} = \frac{1}{2\pi} \int_0^{2\pi} [2r^2 + h^2 + 2hr - 2(r^2 + hr)\cos\theta] d\theta$$

$$d^2_{avg} = 2r^2 + h^2 + 2hr$$

$$= r^2 + (r + h)^2$$

$$d_{sm} = [r^2 + (r + h)^2]^{1/2}$$

For $h = \frac{OD}{2}$ $\quad r = a_{sH}$

$$d_{sm} = [a^2_{sH} + (a_{sH} + \tfrac{OD}{2})^2]^{1/2} \text{ inches}$$

If H = spacing between messenger and ground wires in inches

$$d_{sw} = [a_{sH}^2 + (a_{sH} + H + \frac{OD}{2})^2]^{1/2} \text{ inches}$$

In our installation H = 5'6" = 66"

Thus

$$d_{sw} = [a_{sH}^2 + (a_{sH} + 66 + \frac{OD}{2})^2]^{1/2} \text{ inches}$$

Evaluation of D_{sw}

$$D_{sw} = (d_{sm} * d_{sw})^{1/2} \text{ inches}$$

$$= [a_{sH}^2 + (a_{sH} + \frac{OD}{2})^2][a_{sH}^2 + (a_{sH} + 66 + \frac{OD}{2})^2]^{1/4} \text{ inches}$$

This system can also be represented by 3 branches in parallel plus a short circuit to ground, but the solution equation for Z_o may prove cumbersome to handle and computer time consuming without attaining much more accuracy.

G. Case c': 3 conductor sheathed cable installed aerially suspended from a messenger with earth return (typical of PIAC aerial cables)

In this case, there are 3 possible return paths for zero sequence currents: sheath, messenger, and earth. Thus, it is the same as case c with a change in the definition of the parameters as follows:

$$Z_w = 3r_m + r_e + j.8382 \log \frac{D_e * 12}{GMR_m} \text{ ohms/mile}$$

r_m = resistance of messenger wire

$GMR_m = .779 * a_m$

a_m = radius of messenger wire

$$Z_{cw} = r_e + j.8382 \log \frac{D_e * 12}{d_{cm}} \text{ ohms/mile}$$

$$Z_{sw} = r_e + j.8382 \log \frac{D_e * 12}{d_{sm}} \text{ ohms/mile}$$

$$d_{cm} = \left\{(OD - s\frac{\sqrt{3}}{3}) [\frac{s^2}{4} + (OD + s\frac{\sqrt{3}}{6})^2\right\}^{1/3} \text{ inches}$$

$$d_{sm} = [a_{sH}^2 + (a_{sH} + \frac{OD}{2})^2]^{1/2} \text{ inches}$$

s = GMD of the cable conductors in inches

a_{sH} = radius of the sheath in inches

H. Case d: 3 single conductor non-sheathed cables in steel conduit with earth return (typical for XLP 5 Kv and 15 Kv cables and RHW-USE cables in steel conduit).

In this case, there are two possible return paths for zero sequence currents: pipe and earth. Thus, the case is similar to "case a" substituting the sheath by the pipe and adjusting the definition of the parameters.

$$Z_o = Z_c - \frac{(Z_{cp})^2}{Z_p}$$

Where

$$Z_c = r_c + r_e + j.8382 \log \frac{D_e * 12}{GMR} \text{ ohms/mile}$$

$$GMR = (GMR * GMD^2)^{1/3} \text{ inches}$$

GMD = geometric mean distance of conductors

$$Z_c - Z_{cp} = 3R_p + j\,3X_p \text{ ohms/mile}$$

$$R_p = 15.36 * 29.9 * 5.28/(D_p * 1000) \text{ ohms/mile}$$

$$X_p = 15.36 * 18.1 * 5.28/(D_p * 1000) \text{ ohms/mile}$$

D_p = pipe diameter in inches
$= 2a_p$

$$Z_{cp} = r_e + j.8382 \log \frac{D_e * 12}{a_p} \text{ ohms/mile}$$

$$Z_p = 3R_p + r_e + j(3X_p + .8382 \log \frac{D_e * 12}{a_p}) \text{ ohms/mile}$$

I. Case d': 3 single conductor non-sheathed cables in fiber duct with earth return (typical for XLP and RHW-USE in fiber duct).

In this case, there is one possible return path for zero sequence currents: earth return.

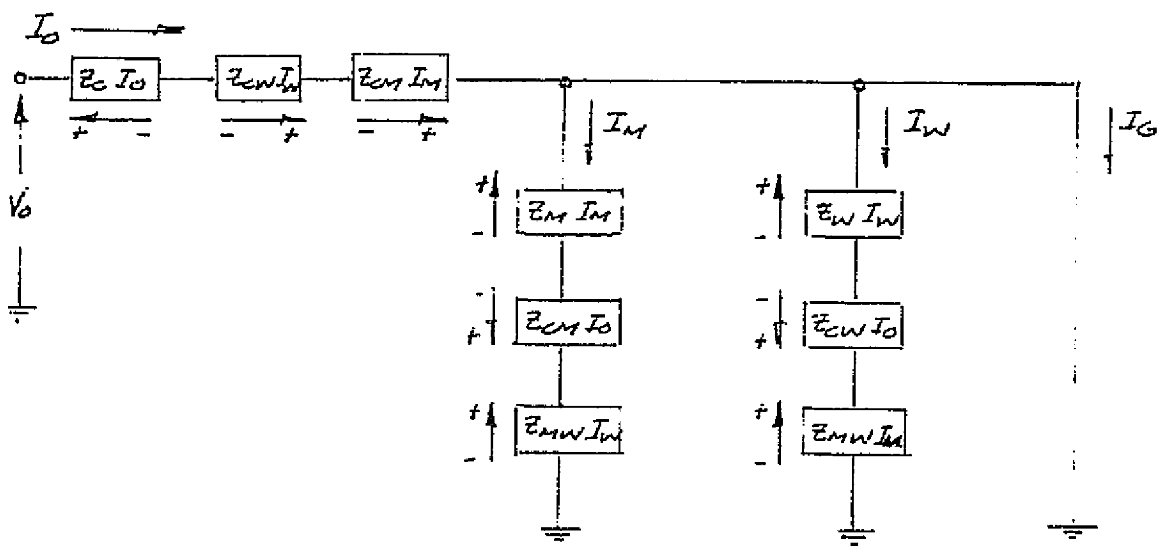
Thus

$$Z_o = Z_c = r_c + r_e + j.8382 \log \frac{D_e * 12}{GMR} \text{ ohms/mile}$$

J. <u>Case e:</u> 3 single conductor non-sheathed cables aerially suspended from a messenger with one ground wire at top with earth return (typical for XLP aerial cables).

In this case, there are 3 possible return paths for zero sequence currents: messenger, ground wire, and earth.

The circuit for this system can be represented by the current flow diagram:



System Equations:

$$I_o = I_m + I_w + I_G$$

$$V_o = I_o (Z_c - Z_{cw}) + I_m (Z_{mw} - Z_{cm}) + I_w (Z_w - Z_{cw})$$

$$V_o = I_o (Z_c - Z_{cm}) + I_m (Z_m - Z_{cm}) + I_w (Z_{mw} - Z_{cw})$$

$$0 = -I_O Z_{cm} + I_m Z_m + I_w Z_{mw}$$

Which are the same equations that define "case c" substituting the sheath (s) by the messenger (m). Thus the solution is

$$Z_o = Z_m \frac{[(Z_c - Z_{cm})(Z_w - Z_{cw}) + (Z_c - Z_{cw})(Z_{cw} - Z_{mw})]}{Z_m (Z_w - Z_{mw}) + Z_{mw} (Z_m - Z_{mw})} +$$

$$+ Z_{mw} \frac{[(Z_c - Z_{cw})(Z_m - Z_{cm}) + (Z_c - Z_{cm})(Z_{cm} - Z_{mw})]}{Z_m (Z_w - Z_{mw}) + Z_{mw} (Z_m - Z_{mw})}$$

$$+ Z_{cm} \frac{[(Z_w - Z_{cw})(Z_m - Z_{cm}) + (Z_{cm} - Z_{mw})(Z_{mw} - Z_{cw})]}{Z_m (Z_w - Z_{mw}) + Z_{mw} (Z_m - Z_{mw})}$$

Parameters Definition:

$$Z_c = r_c + r_e + j.8382 \log \frac{D_e * 12}{GMR} \quad \text{ohms/mile}$$

$$GMR = (GMR_{1c} * GMD^2)^{1/3} \quad \text{inches}$$

$$Z_m = 3r_m + r_e + j \log \frac{D_e * 12}{.779\, a_m} \quad \text{ohms/mile}$$

r_m = resistance of messenger wire in ohms/mile

a_m = radius of messenger wire in inches

$$Z_w = 3r_w + r_e + j \log \frac{D_e * 12}{.779\, a_w} \quad \text{ohms/mile}$$

r_w = resistance of ground wire in ohms/mile

a_w = radius of ground wire in inches

$$Z_{cm} = r_e + j.8382 \log \frac{D_e * 12}{d_{cm}} \quad \text{ohms/mile}$$

$$d_{cm} = \left\{ (h + \frac{OD}{2} - s\frac{\sqrt{3}}{3}) \; [(h + \frac{OD}{2} + s\frac{\sqrt{3}}{6})^2 + \frac{s^2}{4}] \right\}^{1/3} \quad \text{inches}$$

For $h = \frac{OD}{2}$ = height of messenger above conductors in inches

$$d_{cm} = \left\{ (OD - s\frac{\sqrt{3}}{3}) \; [(OD + s\frac{\sqrt{3}}{6})^2 + \frac{s^2}{4}] \right\}^{1/3} \quad \text{inches}$$

Where OD = outside diameter of one cable in inches

s = spacing of conductors in inches

For common installations

$$d_{cm} \approx 1.28 * OD \quad \text{inches}$$

$$Z_{cw} = r_e + j.8382 \ \log \frac{D_e * 12}{d_{cw}} \quad \text{ohms/mile}$$

$$d_{cw} = \left\{ (H + OD - s\frac{\sqrt{3}}{3}) \ [\frac{s^2}{4} + (H + OD + s\frac{\sqrt{3}}{6})^2] \right\}^{1/3} \quad \text{inches}$$

For our installation H = 5'6" = 66" = spacing from messenger to ground wire

Then

$$d_{cw} = \left\{ (66 + OD - s\frac{\sqrt{3}}{3}) \ [\frac{s^2}{4} + (66 + OD + s\frac{\sqrt{3}}{6})^2] \right\}^{1/3} \quad \text{inches}$$

$$Z_{mw} = r_e + j.8382 \ \log \frac{D_e * 12}{H} \quad \text{ohms/mile}$$

$$= r_e + j.8382 \ \log \frac{D_e * 12}{66} \quad \text{ohms/mile}$$

In this case, we could have also reduced the system to 2 return paths considering the messenger and ground wire as one equivalent ground wire. The system will then have a solution given by

$$Z_o = Z_c - \frac{Z_{cw}}{Z_w} \quad \text{ohms/mile}$$

Where

$$Z_c = r_c + r_e + j.8382 \ \log \frac{D_e * 12}{GMR} \quad \text{ohms/mile}$$

$$Z_w = 3r_{weQ} + r_e + j.8382 \ \log \frac{D_e * 12}{GMR_w} \quad \text{ohms/mile}$$

Where

$$GMR_w = (.779 \ a_m * .779 \ a_w * H^2)^{1/4} \quad \text{inches}$$

a_m = radius of messenger wire in inches

a_w = radius of ground wire in inches

H = spacing between messenger and ground wires in inches

$$Z_{cw} = r_e + j.8382 \ \log \frac{D_e * 12}{D_{cw}} \quad \text{ohms/mile}$$

Where

$$D_{cw} = (d_{cm} * d_{cw})^{1/2} \text{ inches}$$

$$D_{cw} = \left\{ (OD - s\frac{\sqrt{3}}{3}) \left[\frac{s^2}{4} + (OD + s\frac{\sqrt{3}}{6})^2 \right] (H + OD - s\frac{\sqrt{3}}{3}) \left[\frac{s^2}{4} + (H + OD + s\frac{\sqrt{3}}{6})^2 \right] \right\}^{1/6}$$

inches

K. Case e': 3 single conductor non-sheathed cables aerially suspended from a messenger with earth return (typical for XLP aerial cables).

In this case, there are two possible return paths for zero sequence currents: messenger and earth. The solution is:

$$Z_o = Z_c - \frac{Z_{cm}}{Z_m} \text{ ohms/mile}$$

Where

$$Z_c = r_c + r_e + j.8382 \log \frac{D_e * 12}{GMR} \text{ ohms/mile}$$

$$GMR = (GMR_{1c} * GMD^2)^{1/3} \text{ inches}$$

$$Z_m = 3r_m + r_e + j.8382 \log \frac{D_e * 12}{.779\, a_m} \text{ ohms/mile}$$

r_m = resistance of messenger wire in ohms/mile

a_m = radius of messenger wire in inches

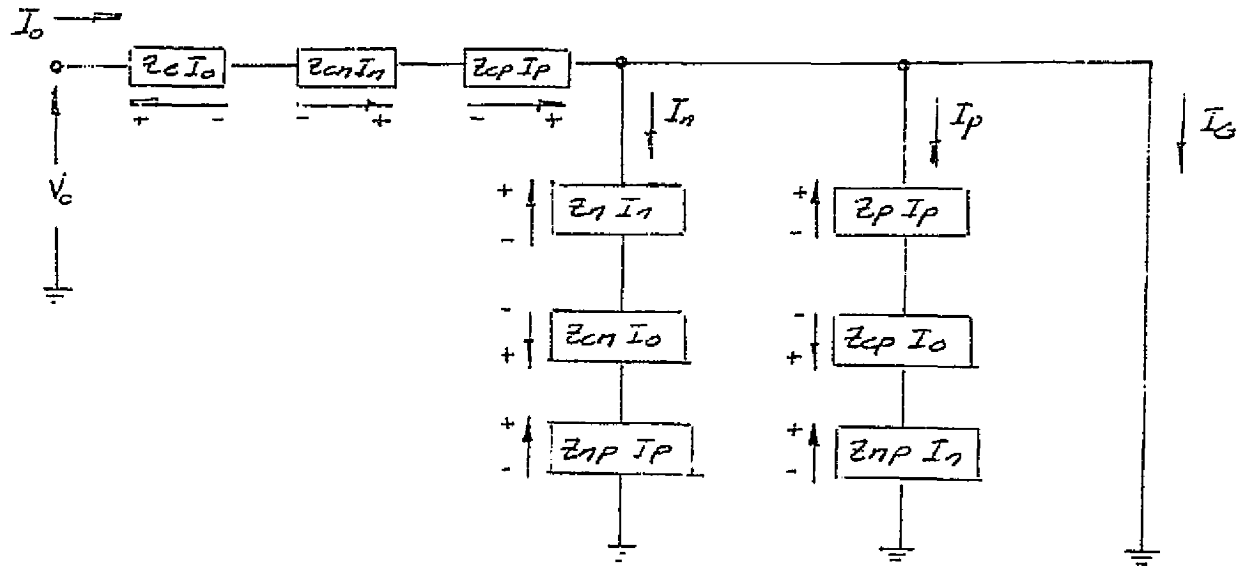
$$Z_{cm} = r_e + j.8382 \log \frac{D_e * 12}{d_{cm}} \text{ ohms/mile}$$

$$d_{cm} = 1.28 * OD \text{ inches}$$

L. Case f: 3 single conductors + one grounded neutral conductor in steel conduit with earth return (typical of RHW-USE cables in steel conduit).

In this case, there are 3 possible return paths for zero sequence currents: the grounded neutral conductor, the pipe, and the earth .

The circuit can be represented by the current flow diagram:



System Equations:

$$I_o = I_n + I_p + I_G$$

$$V_o = I_o\,(Z_c - Z_{cp}) + I_n\,(Z_{np} - Z_{cn}) + I_p\,(Z_p - Z_{cp})$$

$$V_o = I_o\,(Z_c - Z_{cn}) + I_n\,(Z_n - Z_{cn}) + I_p\,(Z_{np} - Z_{cp})$$

$$0 = -I_o Z_{cn} + I_n Z_n + I_p Z_{np}$$

Which are the same equations that describe "case a" substituting the sheath (s) by the neutral conductor (n). Thus, the solution is given by:

$$Z_o = Z_n \;\frac{[(Z_c - Z_{cn})(Z_p - Z_{cp}) + (Z_c - Z_{cp})(Z_{cp} - Z_{np})]}{Z_n\,(Z_p - Z_{np}) + Z_{np}\,(Z_n - Z_{np})}$$

$$+ Z_{np} \;\frac{[(Z_c - Z_{cp})(Z_n - Z_{cn}) + (Z_c - Z_{cn})(Z_{cn} - Z_{np})]}{Z_n\,(Z_p - Z_{np}) + Z_{np}\,(Z_n - Z_{np})}$$

$$+ Z_{cn} \;\frac{[(Z_p - Z_{cp})(Z_n - Z_{cn}) + (Z_{cn} - Z_{np})(Z_{np} - Z_{cp})]}{Z_n\,(Z_p - Z_{np}) + Z_{np}\,(Z_n - Z_{np})}$$

Parameter Definition

$$Z_c = r_c + r_e + j.8382 \log \frac{D_e * 12}{GMR} \text{ ohms/mile}$$

$$GMR = (GMR_{1c} * GMD^2)^{1/3} \text{ inches}$$

$$Z_n = 3r_n + r_e + j.8382 \log \frac{D_e * 12}{GMR_n} \text{ ohms/mile}$$

r_n = resistance of neutral conductor in ohms/mile

GMR_n = geometric mean radius of neutral conductor in inches

$$Z_p - Z_{cp} = 3R_p + j3X_p \text{ ohms/mile}$$

$$R_p = 15.36 * 29.9 * 5.28/(D_p * 1000) \text{ ohms/mile}$$

$$X_p = 15.36 * 18.1 * 5.28/(D_p * 1000) \text{ ohms/mile}$$

$D_p = 2a_p$ = diameter of pipe in inches

$$Z_{cp} = r_e + j.8382 \log \frac{D_e * 12}{a_p} \text{ ohms/mile}$$

$$Z_p = 3R_p + r_e + j\ (3X_p + .8382 \log \frac{D_e * 12}{a_p} \text{ ohms/mile}$$

$$Z_{cn} = r_e + j.8382 \log \frac{D_e * 12}{GMD} \text{ ohms/mile}$$

$$Z_{np} = Z_{cp} \text{ ohms/mile}$$

M. Case f': 3 single conductors + one grounded neutral conductor in fiber duct with earth return (typical for RHW-USE cable in fiber duct).

In this case, there are two possible return paths for zero sequence currents: the grounded neutral and the earth. The solution is given by:

$$Z_o = Z_c - \frac{Z_{cn}}{Z_n} \text{ ohms/mile}$$

Where

$$Z_c = r_c + r_e + j.8382 \log \frac{D_e * 12}{GMR} \text{ ohms/mile}$$

$$GMR = (GMR_{1c} * GMD^2)^{1/3} \quad \text{inches}$$

$$Z_n = 3r_n + r_e + j.8382 \quad \log \frac{D_e * 12}{GMR_n} \quad \text{ohms/mile}$$

r_n = resistance of neutral conductor in ohms/mile

GMR_n = geometric mean radius of neutral conductor in inches

$$Z_{cn} = r_e + j.8382 \quad \log \frac{D_e * 12}{GMD} \quad \text{ohms/mile}$$

5. Summary of Network Configuration and Bus Designations

A. Bus Code Designations and Voltage Levels

The following bus on the network one line diagram:

Launching Complex 8 - 905

Industrial Area 2008 - 2915

All bus codes are indexed with a voltage designation as follows:

Bus Voltage	First Symbol in Bus Code
13,800	A
4,160	B
480	C
208	D
115,000	E
13,680	F
13,320	G
13,200	H
2,400	J
120/240	K

Voltage levels at specific buses are as follows:

13.8 Kv Buses (A)

8 thru 12, 14 thru 16, 18 thru 33, 35, 38, 39, 43 thru 49, 51 thru 54, 56 thru 91, 98, 99, 116 thru 122, 124 thru 132, 137 thru 142, 146 thru 155, 158 thru 169, 174, 175, 178, 179, 181, 188, 192, 193, 198, 199, 201, 203, 205 thru 206, 208, 211, 214, 216, 218, 220, 222 thru 226, 228, 229, 231, 233, 235, 236, 238 thru 240, 242, 244, 245, 247, 249 thru 252, 255, 257, 261 thru 265, 267, 268, 271, 272, 274, 275, 278 thru 280, 283 thru 285, 288, 289, 290, 299 thru 303, 325, 326, 340 thru 342, 353, 901 thru 905

4.16 Kv Buses (B)

100 thru 115, 183, 197, 246, 248, 286, 287, 297, 298, 304, 328, 334, 335, 337, 338, 343, 344, 347 thru 352

480 V Buses (C)

13, 17, 34, 36, 37, 40 thru 42, 50, 55, 92 thru 97, 123, 133 thru 136, 143 thru 145, 156, 157, 170 thru 173, 176, 182, 184 thru 187, 189 thru 191, 194 thru 196, 200, 202, 204, 207, 209, 210, 213, 215, 217, 219, 221, 227, 230, 232, 234, 237, 241, 243, 253, 254, 258 thru 260, 266, 269, 270, 273, 276, 277, 281, 282, 291 thru 296, 305 thru 324, 327, 329 thru 333, 336, 339, 345, 346, 354 thru 374, 376 thru 385, 392 thru 418, 420 thru 422, 424 thru 458, 460 thru 468, 470 thru 482, 484 thru 505, 507 thru 509, 511 thru 515, 517 thru 524, 526 thru 545, 548 thru 550, 650 thru 657, 659 thru 663, 665, 666, 668 thru 671, 673 thru 678, 680, 682, 683, 685, 686, 688 thru 691, 693 thru 704, 706, 707, 709 thru 711, 713, 718 thru 722, 730, 731, 552 thru 583, 585 thru 628, 631 thru 640

208 V Buses (D)

177, 180, 212, 256, 386 thru 391, 419, 423, 459, 469, 483, 506, 510, 516, 525, 547, 551, 641 thru 649, 658, 664, 667, 672, 679, 692, 708, 712, 714, 715, 584

115 Kv Bus (E)

5

Kennedy Space Center Industrial Area Voltage Levels of Coded Buses

Note: All buses shall be coded starting with 2008

115 Kv (E)

4

13.8 Kv (A) (This network section normally connected to VABR 609)

2026, 2098, 2102, 2104, 2106, 2108, 2110, 2112, 2115, 2117, 2119, 2121, 2123, 2125, 2129, 2131, 2133, 2135, 2145, 2139, 2141, 2143, 2147, 2149, 2151, 2153 thru 2169, 2172, 2197, 2199, 2201, 2204, 2210, 2211, 2915, 2916, 2917

13.68 Kv (F) (This network section normally connected to VABR 609)

2113, 2127, 2137

13.32 Kv (G)

2208

13.2 Kv (H)

2008, 2009, 2011 thru 2025, 2027 thru 2086, 2088, 2091, 2093, 2094, 2096, 2097, 2100, 2170, 2174, 2176, 2178, 2180, 2182, 2184, 2186, 2188, 2191, 2193, 2195, 2214 thru 2218, 2220, 2222, 2224, 2228, 2230, 2233, 2236, 2237, 2241, 2243 thru 2249, 2267, 2272, 2278, 2279, 2280, 2281, 2283, 2285, 2287, 2288, 2293 thru 2296, 2299, 2301, 2303, 2305, 2307, 2309, 2311, 2313, 2315, 2317, 2319, 2321, 2323, 2325, 2327, 2329, 2331, 2333, 2335 thru 2349, 2353, 2355, 2357, 2359, 2361, 2363, 2365, 2367, 2369, 2371, 2373, 2375, 2377, 2379, 2381, 2383, 2385, 2387, 2389, 2391 thru 2431, 2433, 2435, 2437, 2439, 2441, 2443, 2445, 2447, 2456 thru 2463, 2465, 2467, 2469, 2471, 2473, 2475, 2478, 2481, 2483 thru 2494, 2501 thru 2504, 2506, 2508, 2510, 2514, 2516, 2517 thru 2524, 2526, 2528, 2530, 2532, 2534, 2536 thru 2541, 2852, 2901 thru 2914,

2.4 Kv (J)

2271, 2273, 2274, 2289, 2290, 2291, 2297, 2298, 2350 thru 2352, 2472, 2474, 2496, 2497, 2499, 2500

480V (C)

2087, 2092, 2095, 2122, 2128, 2187, 2189, 2190, 2192, 2209, 2221, 2231, 2232, 2235, 2238, 2240, 2242, 2250 thru 2259, 2261, 2263, 2264, 2268, 2269, 2270, 2275, 2292, 2302, 2308, 2316, 2318, 2320, 2328, 2356, 2370, 2378, 2388, 2432, 2436, 2444, 2450 thru 2452, 2454, 2466, 2468, 2470, 2476, 2477, 2479, 2480, 2482, 2512, 2531, 2533, 2542 thru 2679, 2681 thru 2850, 2853

208V (D)

2089, 2090, 2105, 2114, 2132, 2134, 2136, 2138, 2148, 2150, 2152, 2171, 2173, 2175, 2177, 2179, 2194, 2196, 2198, 2200, 2202, 2203, 2205, 2219, 2226, 2227, 2229, 2234, 2239, 2260, 2262, 2265, 2266, 2276, 2277, 2282, 2284, 2286, 2300, 2304, 2306, 2310, 2312, 2314, 2322, 2324, 2326, 2330, 2332, 2334, 2354, 2358, 2360, 2362, 2364, 2366, 2368, 2372, 2374, 2376, 2380, 2382, 2384, 2386, 2390, 2434, 2438, 2440, 2442, 2446, 2448, 2453, 2464, 2505, 2507, 2509, 2511, 2513, 2515, 2525, 2527, 2529, 2535, 2851

120/240V - 1Ø (K)

2099, 2101, 2103, 2107, 2109, 2111, 2116, 2118, 2120, 2124, 2126, 2130, 2140, 2142, 2144, 2146, 2181, 2183, 2185, 2223, 2225, 2449, 2455

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
5	115 Kv	115 Kv FPLCO Line at C-5 Substation
8	13.8 Kv	Instrumentation Bus at C-5 Substation
9	13.8 Kv	Industrial Bus at C-5 Substation
10	13.8 Kv	VAB Recloser Bus
11	13.8 Kv	LBS # 301 Industrial Bus
12	13.8 Kv	VABR Substation # 833-300 KVA Transformer "B"
13	480 V	VABR Substation # 833 Transformer "B"
14	13.8 Kv	VABR Substation # 833-300 KVA Transformer "A"
15	13.8 Kv	LBS # 718 Industrial Bus
16	13.8 Kv	Substation # 832-500 KVA Transformer Maintenance Shop
17	480 V	Substation # 832 Transformer Maintenance Shop
18	13.8 Kv	Switchgear # 700 Industrial Bus
19	13.8 Kv	LBS # 724 Industrial Bus
20	13.8 Kv	LBS # 771 Industrial Bus
21	13.8 Kv	LBS # 723 Industrial Bus
22	13.8 Kv	Substation # 800-1000 KVA Transformer "A"
23	13.8 Kv	Substation # 802-1500 KVA Transformer "A"
24	13.8 Kv	Substation # 804-750 KVA Transformer "A"
25	13.8 Kv	Substation # 818-1000 KVA Transformer "A"
26	13.8 Kv	Substation # 804-1000 KVA Transformer "B"
27	13.8 Kv	Substation # 800-1000 KVA Transformer "B"
28	13.8 Kv	Substation # 802-1500 KVA Transformer "B"
29	13.8 Kv	Substation # 818-1000 KVA Transformer "B"
30	13.8 Kv	LBS # 750-ML Interface
31	13.8 Kv	LBS # 752-ML Interface
32	13.8 Kv	LBS # 742 Industrial Bus
33	13.8 Kv	Substation # 801-750 KVA Transformer "A"
34	480 V	Substation # 800 Transformer "A"
35	13.8 Kv	Substation # 801-750 KVA Transformer "B"
36	480 V	Substation # 801 Transformer "A"
37	480 V	Substation # 802 Transformer "A"
38	13.8 Kv	Substation # 803-1000 KVA Transformer "A"
39	13.8 Kv	Substation # 803-1000 KVA Transformer "B"

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
40	480 V	Substation # 803 Transformer "A"
41	480 V	Substation # 804 Transformer "A"
42	480 V	Substation # 818 Transformer "A"
43	13.8 Kv	LBS # 725 Industrial Bus
44	13.8 Kv	Substation # 830-750 KVA Transformer "B"
45	13.8 Kv	WYE on Feeder # 610 at LBS # 727
46	13.8 Kv	LBS # 727 Industrial Bus
47	13.8 Kv	LBS # 728 Industrial Bus
48	13.8 Kv	LBS # 740 Industrial Bus
49	13.8 K	LBS # 743 Industrial Bus
50	480 V	Substation # 830 Transformer "B"
51	13.8 Kv	Substation # 830-750 KVA Transformer "A"
52	13.8 Kv	Switchgear # 703 Industrial Bus and LBS # 721
53	13.8 Kv	Substation # 820 (LCC)-1500 KVA Transformer "A"
54	13.8 Kv	Substation # 820 (LCC)-1500 KVA Transformer "B"
55	480 V	Substation # 820 (LCC) Transformer "A"
56	13.8 Kv	Switching Sta. #707 Feeder #605 Industrial Bus
57	13.8 Kv	Normal Switch at Emergency Power Cubicle # 706
58	13.8 Kv	LBS # 762 Industrial Bus
59	13.8 Kv	WYE on Feeder # 607 between LBS # 762 and # 729
60	13.8 Kv	Substation # 888-75 KVA Transformer
61	13.8 Kv	Substation # 887-225 KVA Transformer
62	13.8 Kv	LBS # 729 Industrial Bus
63	13.8 Kv	WYE on Feeder # 607 between LBS # 729 and SS # 879
64	13.8 Kv	Substation # 882 (LCC)-112.5 KVA Transformer
65	13.8 Kv	WYE on Feeder # 607 at Substation # 876
66	13.8 Kv	Substation # 876-45 KVA Transformer
67	13.8 Kv	Substation # 877-45 KVA Transformer
68	13.8 Kv	WYE on Feeder # 607 at Substation # 879
69	13.8 Kv	WYE on Feeder # 607 at Substation # 870
70	13.8 Kv	WYE on Feeder # 607 at Substation # 870
71	13.8 Kv	Substation # 870-300 KVA Transformer
72	13.8 Kv	Substation # 871-45 KVA Transformer
73	13.8 Kv	Substation # 873-225 KVA Transformer
74	13.8 Kv	Substation # 883-45 KVA Transformer
75	13.8 Kv	Substation # 872-300 KVA Transformer
76	13.8 Kv	WYE on Feeder # 607 at Substation # 872
77	13.8 Kv	WYE on Feeder # 607 at Substation # 872
78	13.8 Kv	WYE on Feeder # 607 at Substation # 874
79	13.8 Kv	Substation # 875-45 KVA Transformer
80	13.8 Kv	Substation # 874-45 KVA Transformer

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
81	13.8 Kv	Substation # 880-300 KVA Transformer
82	13.8 Kv	WYE on Feeder # 607 at Substation # 884
83	13.8 Kv	WYE on Feeder # 607 at Substation # 878
84	13.8 Kv	Substation # 879-45 KVA Transformer
85	13.8 Kv	Substation # 881-225 KVA Transformer
86	13.8 Kv	LBS # 773 Feeder # 604 Industrial
87	13.8 Kv	LBS # 773 Feeder # 520 Instrumentation
88	13.8 Kv	Substation # 821 (LCC)-1000 KVA Transformer "A"
89	13.8 Kv	LBS # 774 Feeder # 520 Instrumentation
90	13.8 Kv	LBS # 774 Feeder # 607 Industrial
91	13.8 Kv	Substation # 821 (LCC)-1000 KVA Transformer "B"
92	480 V	Substation # 821 Transformer "A"
93	480 V	Substation # 882 Transformer
94	480 V	Substation # 876 Transformer
95	480 V	Substation # 877-45 KVA Transformer
96	480 V	Substation # 870-300 KVA Transformer
97	480 V	Substation # 871-45 KVA Transformer
98	13.8 Kv	Substation # 829-7500 KVA Transformer "A"
99	13.8 Kv	Substation # 829-7500 KVA Transformer "B"
100	4.16 Kv	Substation # 829 Transformer "A"
101	4.16 Kv	Utility Annex Motor Control Center "A" Bus
102	4.16 Kv	350 HP Synchronous Air Compressor Motor # 2 at Utility Annex MCC-A
103	4.16 Kv	350 HP Synchronous Air Compressor Motor # 1 at Utility Annex MCC-A
104	4.16 Kv	2500 HP Synchronous Refrigerator # 3 at Utility Annex MCC-A
105	4.16 Kv	2500 HP Synchronous Refrigerator # 4 at Utility Annex MCC-A
106	4.16 Kv	450 HP Induction Condensate Water Pump # 4 at Utility Annex MCC
107	4.16 Kv	Utility Annex Motor Control Center "B" Bus
108	4.16 Kv	550 HP Induction Condensate Water Pump # 3 at Utility Annex MCC-B
109	4.16 Kv	450 HP Induction Condensate Water Pump # 2 at Utility Annex MCC-B
110	4.16 Kv	450 HP Induction Condensate Water Pump # 1 at Utility Annex MCC-B
111	4.16 Kv	2500 Hp Synchronous Refrigerator # 2 at Utility Annex MCC-B
112	4.16 Kv	2500 HP Synchronous Refrigerator # 1 at Utility Annex MCC-B
113	4.16 Kv	450 HP Induction Chilled Water Pump # 3 at Utility Annex MCC-B
114	4.16 Kv	450 HP Induction Chilled Water Pump # 2 at Utility Annex MCC-B

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
115	4.16 Kv	450 HP Induction Chilled Water Pump # 1 at Utility Annex MCC-B
116	13.8 Kv	WYE on Feeder # 607 at LBS # 744
117	13.8 Kv	LBS # 745 Industrial Bus
118	13.8 Kv	LBS # 745 Instrumentation Bus
119	13.8 Kv	Substation # 814-500 KVA Transformer "B"
120	13.8 Kv	LBS # 744 Industrial Bus
121	13.8 Kv	LBS # 744 Instrumentation Bus
122	13.8 Kv	Substation # 814-500 KVA Transformer "A"
123	480 V	Substation # 814 Transformer "A"
124	13.8 Kv	LBS # 741 Industrial Bus
125	13.8 Kv	Substation # 806-1000 KVA Transformer "B"
126	13.8 Kv	Substation # 808-1500 KVA Transformer "B"
127	13.8 Kv	Substation # 810-750 KVA Transformer "B"
128	13.8 Kv	Substation # 817-1000 KVA Transformer "A"
129	13.8 Kv	Substation # 806-1000 KVA Transformer "A"
130	13.8 Kv	Substation # 808-1500 KVA Transformer "A"
131	13.8 Kv	Substation # 810-750 KVA Transformer "A"
132	13.8 Kv	Substation # 817-1000 KVA Transformer "B"
133	480 V	Substation # 806 Transformer "A"
134	480 V	Substation # 808 Transformer "A"
135	480 V	Substation # 810 Transformer "A"
136	480 V	Substation # 817 Transformer "B"
137	13.8 Kv	Substation # 807-1000 KVA Transformer "A"
138	13.8 Kv	Substation # 807-1000 KVA Transformer "B"
139	13.8 Kv	Substation # 809-1000 KVA Transformer "A"
140	13.8 Kv	Substation # 809-1000 KVA Transfomer "B"
141	13.8 Kv	Substation # 811-1000 KVA Transformer "A"
142	13.8 Kv	Substation # 811-1000 KVA Transformer "B"
143	480 V	Substation # 807 Transformer "A"
144	480 V	Substation # 809 Transformer "B"
145	480 V	Substation # 811 Transformer "A"
146	13.8 Kv	LBS # 717 Industrial Bus
147	13.8 Kv	LBS # 719 Industrial Bus
148	13.8 Kv	LBS # 756 M. L. Interface Industrial Bus
149	13.8 Kv	LBS # 754 M. L. Interface Industrial Bus
150	13.8 Kv	LBS # 727 Instrumentation Bus
151	13.8 Kv	Substation # 812-500 KVA Transformer "A"
152	13.8 Kv	Substation # 812-500 KVA Transformer "B"
153	13.8 Kv	Substation # 816-1500 KVA Transformer "A"
154	13.8 Kv	Substation # 816-1500 KVA Transformer "B"
155	13.8 Kv	LBS # 728 Instrumentation Bus
156	480 V	Substation # 812 Transformer "A"
157	480 V	Substation # 816 Transformer "A"
158	13.8 Kv	LBS # 743 Instrumentation Bus
159	13.8 Kv	LBS # 755 M. L. Interface Instrumentation Bus
160	13.8 Kv	LBS # 757 M. L. Interface Instrumentation Bus

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
161	13.8 Kv	LBS # 726 Industrial Bus
162	13.8 Kv	LBS # 726 Instrumentation Bus
163	13.8 Kv	LBS # 751 M. L. Interface Instrumentation
164	13.8 Kv	LBS # 753 M. L. Interface Instrumentation
165	13.8 Kv	LBS # 760 Industrial Bus
166	13.8 Kv	LBS # 770 Industrial Bus
167	13.8 Kv	LBS # 775 Industrial Bus
168	13.8 Kv	Substation # 825-150 KVA Transformer
169	13.8 Kv	Substation # 824-225 KVA Transformer
170	480 V	Substation # 823 Transformer
171	480 V	Substation # 824 Transformer
172	480 V	Substation # 825 Transformer
173	480 V	Substation # 822 Transformer
174	13.8 Kv	Substation # 826-1000 KVA Transformer
175	13.8 Kv	Substation # 827-300 KVA Transformer
176	480 V	Substation # 826 Transformer
177	208 V	Substation # 827 Transformer
178	13.8 Kv	Instrumentation Switchgear # 704
179	13.8 Kv	LBS # 761 Instrumentation
180	208 V	Substation # 828 Transformer
181	13.8 Kv	1200 Kw Emergency Generator
182	480 V	Substation # 888 Transformer
183	4.16 Kv	Substation # 924-2 Transformer
184	480 V	Substation # 926 Transformer "B"
185	480 V	Substation # 950 Transformer
186	480 V	Substation # 1054 Transformer
187	480 V	Substation # 872 Transformer
188	13.8 Kv	Substation # 1054-225 KVA Transformer
189	480 V	Substation # 883 Transformer
190	480 V	Substation # 922 Transformer "A"
191	480 V	Substation # 873 Transformer
192	13.8 Kv	Switching Station # 1002 Instrumentation Bus
193	13.8 Kv	Switching Station # 1002 Instrumentation Bus
194	480 V	Substation # 874 Transformer
195	480 V	Substation # 925 Transformer "B"
196	480 V	Substation # 875 Transformer
197	4.16 Kv	Tie between Substation # 924-1 and Substation # 927
198	13.8 Kv	LBS # 1024 Industrial
199	13.8 Kv	Substation # 878-300 KVA Transformer
200	480 V	Substation # 878 Transformer
201	13.8 Kv	Switching Station # 902 Industrial Bus # 1
202	480 V	Substation # 879 Transformer
203	13.8 Kv	Switching Station # 900 Industrial Bus # 2
204	480 V	Substation # 881 Transformer

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
205	13.8 Kv	Switching Station # 900 Instrumentation Bus
206	13.8 Kv	Switching Station # 902 Instrumentation Bus
207	480 V	Substation # 880 Transformer
208	13.8 Kv	Substation # 884-45 KVA Transformer
209	480 V	Substation # 884 Transformer
210	480 V	Substation # 887 Transformer
211	13.8 Kv	Substation # 831-750 KVA Transformer
212	208 V	LBS # 719-225 KVA Transformer
213	480 V	Substation # 831 Transformer
214	13.8 Kv	Substation # 835-2000 KVA Transformer
215	480 V	Substation # 835 Transformer
216	13.8 Kv	Substation # 836-2000 KVA Transformer
217	480 V	Substation # 836 Transformer
218	13.8 Kv	Substation # 837-2000 KVA Transformer
219	480 V	Substation # 837 Transformer
220	13.8 Kv	Substation # 838-1500 KVA Transformer
221	480 V	Substation # 838 Transformer
222	13.8 Kv	Switching Station # 900 Industrial Bus # 1
223	13.8 Kv	Substation # 922-750 KVA Transformer "B"
224	13.8 Kv	Substation # 922-750 KVA Transformer "A"
225	13.8 Kv	Switching Station # 1002 Industrial Bus # 2
226	13.8 Kv	Switching Station # 902 Industrial Bus # 2
227	480 V	Substation # 922 Transformer "B"
228	13.8 Kv	MSS Power Interface Pad A Industrial Bus # 1
229	13.8 Kv	Substation # 839-300 KVA Transformer
230	480 V	Substation # 839 Transformer
231	13.8 Kv	Substation # 952-2, 2500/3125 KVA Transformer
232	480 V	Substation # 952-2 Transformer
233	13.8 Kv	Substation # 952-1, 2000 KVA Transformer
234	480 V	Substation # 953 Transformer
235	13.8 Kv	Substation # 953-300 KVA Transformer
236	13.8 Kv	Substation # 951-2000 KVA Transformer
237	480 V	Substation # 951 Transformer
238	13.8 Kv	Substation # 950-2000 KVA Transformer
239	13.8 Kv	Substation # 926-750 KVA Transformer "A"
240	13.8 Kv	Substation # 926-750 KVA Transformer "B"
241	480 V	Substation # 926 Transformer "A"
242	13.8 Kv	Substation # 925-1000 KVA Transformer "B"

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
243	480 V	Substation # 925 Transformer "A"
244	13.8 Kv	Substation # 925-1000 KVA Transformer "A"
245	13.8 Kv	Substation # 924-1, 2500 KVA Transformer "A"
246	4.16 Kv	Substation # 924-1 Transformer
247	13.8 Kv	Substation # 924-2, 2500 KVA Transformer "B"
248	13.8 Kv	Substation # 927-1500 KVA Transformer
249	4.16 Kv	Substation # 927 Transformer
250	13.8 Kv	Substation # 921-750 KVA Transformer "B"
251	13.8 Kv	Substation # 920-500 KVA Transformer "B"
252	13.8 Kv	Substation # 921-750 KVA Transformer "A"
253	480 V	Substation # 920 Transformer "A"
254	480 V	Substation # 921 Transformer "A"
255	13.8 Kv	Substation # 954-300 KVA Transformer
256	208 V	Substation # 954 Transformer
257	13.8 Kv	LBS # 929 Instrumentation
258	480 V	Substation # 928 Mobile Launcher Industrial Transformer
259	480 V	Substation # 929 Mobile Launcher Instrumentation Transformer
260	480 V	Substation # 923 Mobile Service Structure Transformer "A"
261	13.8 Kv	Substation # 923 Mobile Service Structure 2000 KVA Transformer "B"
262	13.8 Kv	Switching Station # 1001 Instrumentation Bus
263	13.8 Kv	Switching Station # 1001 Industrial Bus # 1
264	13.8 Kv	Switching Station # 1001 Industrial Bus # 2
265	13.8 Kv	Substation # 1050-2000 KVA Transformer "B"
266	480 V	Substation # 1050 Transformer
267	13.8 Kv	Substation # 1050-2000 KVA Transformer "A"
268	13.8 Kv	Substation # 1030-750 KVA Transformer
269	480 V	Substation # 1030 Transformer
270	480 V	Substation # 1029 Transformer
271	13.8 Kv	Substation # 1029-750 KVA Transformer
272	13.8 Kv	Substation # 1023-500 KVA Transformer 2
273	480 V	Substation # 1023 Transformer 2
274	13.8 Kv	Substation # 1023-500 KVA Transformer 1
275	13.8 Kv	Substation # 1053-300 KVA Transformer
276	480 V	Substation # 1053 Transformer
277	480 V	Substation # 1052 Transformer 2

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
278	13.8 Kv	Substation # 1053-2500 KVA Transformer 2
279	13.8 Kv	Substation # 1053-2500 KVA Transformer 1
280	13.8 Kv	Substation # 1031-1500 KVA Transformer
281	480 V	Substation # 1031 Transformer
282	480 V	Substation # 1032 Transformer
283	13.8 Kv	Substation # 1032-1500 KVA Transformer
284	13.8 Kv	Tie Feeders # 606 and # 612 For Mobile Launcher Power Interface
285	13.8 Kv	Substation # 1020-2500 KVA Transformer
286	4.16 Kv	Substation # 1020 Transformer
287	4.16 Kv	Substation # 1020 Tie Between Substation # 1020 and Substation # 1021
288	13.8 Kv	Substation # 1021-2500 KVA Transformer 1
289	13.8 Kv	Substation # 1021-2500 KVA Transformer 2
290	13.8 Kv	Substation # 920-500 KVA Transformer "A"
291	480 V	Substation # 920 Transformer "B"
292	480 V	Substation # 921 Transformer "B"
293	480 V	Substation # 923 Mobile Service Structure Transformer
294	480 V	Substation # 1050 Transformer "A"
295	480 V	Substation # 1023 Transformer 1
296	480 V	Substation # 1052 Transformer 1
297	4.16 Kv	Substation # 1021 Transformer 1
298	4.16 Kv	Substation # 1021 Transformer 2
299	13.8 Kv	Industrial Switchgear # 701
300	13.8 Kv	Switching Station # 707 Feeder # 611 Industrial Bus
301	13.8 Kv	Industrial Switchgear # 702
302	13.8 Kv	Instrumentation Switchgear # 705
303	13.8 Kv	LBS # 772 Industrial
304	4.16 Kv	Substation # 829 Utility Annex Transformer "B"
305	480 V	Substation # 833 VABR Transformer "B"
306	480 V	Substation # 830 Transformer "B"
307	480 V	Substation # 800 Transformer "B"
308	480 V	Substation # 802 Transformer "B"
309	480 V	Substation # 804 Transformer "B"
310	480 V	Substation # 818 Transformer "B"
311	480 V	Substation # 820 LCC Transformer "B"
312	480 V	Substation # 806 Transformer "B"
313	480 V	Substation # 808 Transformer "B"
314	480 V	Substation # 810 Transformer "B"
315	480 V	Substation # 817 Transformer "A"
316	480 V	Substation # 801 Transformer "B"
317	480 V	Substation # 803 Transformer "B"
318	480 V	Substation # 821 LCC Transformer "B"
319	480 V	Substation # 814 Transformer "B"
320	480 V	Substation # 807 Transformer "B"
321	480 V	Substation # 809 Transformer "A"
322	480 V	Substation # 811 Transformer "B"
323	480 V	Substation # 812 Transformer "B"
324	480 V	Substation # 816 Transformer "B"

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
325	13.8 Kv	LBS # 928-2
326	13.8 Kv	MSS Interface Pad A Industrial Bus # 2
327	480 V	Substation # 950 Tie Between Substation # 950 and Substation # 951
328	4.16 Kv	Substation # 924-1 Tie Between Substation # 924-1 and Substation # 927
329	480 V	Substation # 952 Transformer
330	480 V	Substation # 952 Tie Between Substation # 952 and Substation # 953
331	480 V	Substation # 1030 Tie Between Substation # 1030 and Substation # 1029
332	480 V	Substation # 1032 Tie Between Substation # 1032 and Substation # 1031
333	480 V	Substation # 1053 Tie Between Substation # 1053 and Substation # 1052
334	4.16 Kv	2500 HP Induction Lox Pump at Substation # 1021-1
335	4.16 Kv	200 Hp Induction Lox Pump at Substation # 1021-1
336	480 V	75 KVA Clutch Transformer at Substation # 1021-1
337	4.16 Kv	2500 HP Induction Lox Pump at Substation # 1021-2
338	4.16 Kv	200 HP Induction Loc Pump at Substation # 1021-2
339	480 V	75 KVA Clutch Transformer at Substation # 1021-2
340	13.8 Kv	Substation # 828-225 KVA Transformer
341	13.8 Kv	Substation # 822-112.5 KVA Transformer
342	13.8 Kv	Substation # 825-225 KVA Transformer
343	4.16 Kv	1000 HP Induction ML Water Pump at Substation # 927
344	4.16 Kv	500 HP Induction Firex Pump at Substation # 927
345	480 V	75 KVA Clutch Transformer at Substation # 924-1
346	480 V	75 KVA Clutch Transformer at Substation # 924-2
347	4.16 Kv	2500 HP Induction Lox Pump # 1 at Substation # 924-1
348	4.16 Kv	200 HP Induction Lox Pump # 2 at Substation # 924-1
349	4.16 Kv	2500 HP Induction Lox Pump # 2 at Substation # 924-2
350	4.16 Kv	300 HP Induction Lox Pump # 1 at Substation # 924-2
351	4.16 Kv	1000 HP Induction ML Water Pump at Substation # 1020
352	4.16 Kv	400 HP Induction Firex Pump at Substation # 1020
353	13.8 Kv	Substation # 929 ML Instrumentation 1000 KV Transformer

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
354 thru 369	480 V	Substation # 952 Low Voltage Network
370	480 V	Substation # 953 Low Voltage Network
371 thru 373	480 V	Substation # 952 Low Voltage Network
374	480 V	Substation # 926 Low Voltage Network
375		Not Used
376	480 V	Substation # 926 Low Voltage Network
377 thru 379	480 V	Substation # 922 Low Voltage Network
380	480 V	Substation # 925 Low Voltage Network
381	480 V	Substation # 920 Low Voltage Network
382	480 V	Substation # 921 Low Voltage Network
383	480 V	Substation # 950 Low Voltage Network
384	480 V	Substation # 951 Low Voltage Network
385	480 V	Substation # 954, 150 KVA Transformer
386 thru 391	208 V	Substation # 954 Low Voltage Network
392 thru 409	480 V	Substation # 800 Low Voltage Network
410	480 V	Substation # 800-100HP Chiller
411 thru 417	480 V	Substation # 801 Low Voltage Network
418	480 V	Substation # 871 Low Voltage Network
419	208 V	Substation # 871 Low Voltage Network
420 thru 422	480 V	Substation # 870 Low Voltage Network
423	208 V	Substation # 870 Low Voltage Network
424 thru 436	480 V	Substation # 802 Low Voltage Network
437 thru 451	480 V	Substation # 803 Low Voltage Network
452 thru 457	480 V	Substation # 812 Low Voltage Network
458	480 V	Substation # 883 Low Voltage Network
459	208 V	Substation # 883 Low Voltage Network
460 thru 465	480 V	Substation # 873 Low Voltage Network
466 thru 468	480 V	Substation # 872 Low Voltage Network
469	208 V	Substation # 872 Low Voltage Network
470 thru 477	480 V	Substation # 804 Low Voltage Network
478 thru 481	480 V	Substation # 874 Low Voltage Network
482	480 V	Substation # 875 Low Voltage Network
483	208 V	Substation # 875 Low Voltage Network
484 thru 496	480 V	Substation # 806 Low Voltage Network
487 thru 504	480 V	Substation # 807 Low Voltage Network
505	480 V	Substation # 877 Low Voltage Network
506	208 V	Substation # 877 Low Voltage Network
507 thru 509	480 V	Substation # 876 Low Voltage Network
510	208 V	Substation # 876 Low Voltage Network
511 thru 515	480 V	Substation # 808 Low Voltage Network
516	208 V	Substation # 808 Low Voltage Network
517 thru 524	480 V	Substation # 808 Low Voltage Network
525	208 V	Substation # 808 Low Voltage Network
526	480 V	Substation # 808-100 HP Chiller
527 thru 539	480 V	Substation # 809 Low Voltage Network
540 thru 545	480 V	Substation # 814 Low Voltage Network
546	480 V	Not Used
547	208 V	Substation # 879 Low Voltage Network

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
548 thru 550	480 V	Substation # 878 Low Voltage Network
551	208 V	Substation # 878 Low Voltage Network
552 thru 557	480 V	Substation # 881 Low Voltage Network
558 thru 570	480 V	Substation # 810 Low Voltage Network
571 thru 579	480 V	Substation # 811 Low Voltage Network
580 thru 583	480 V	Substation # 880 Low Voltage Network
584	208 V	Substation # 884 Low Voltage Network
585	480 V	Substation # 884 Low Voltage Network
586 thru 595	480 V	Substation # 818 Low Voltage Network
596 thru 601	480 V	Substation # 816 Low Voltage Network
602 thru 609	480 V	Substation # 817 Low Voltage Network
610 thru 611	480 V	Substation # 887 Low Voltage Network
612 thru 614	480 V	Substation # 887 and Substation # 818 Low Voltage Network
615 thru 619	480 V	Substation # 830 Low Voltage Network
620	480 V	Substation # 830-125 HP WC Fan # 5
621	480 V	Substation # 830-125 HP WC Fan # 6
622	480 V	Substation # 830-75 HP WC Fan # 1
623	480 V	Substation # 830 Low Voltage Network
624	480 V	Substation # 830-75 HP WC Fan # 2
625	480 V	Substation # 830-75 HP WC Fan # 3
626	480 V	Substation # 830-75 HP WC Fan # 4
627	480 V	Substation # 833 Low Voltage Network
628		Not Used
629		Not Used
630		Not Used
631	480 V	Substation # 833 Low Voltage Network
632	480 V	Substation # 822 Low Voltage Network
633 thru 637	480 V	Substation # 823 Low Voltage Network
638	480 V	Substation # 825 Low Voltage Network
639 thru 640	480 V	Substation # 839 Low Voltage Network
641 thru 643	208 V	Substation # 827 Low Voltage Network
644	208 V	Substation # 828 Low Voltage Network
645 thru 649	208 V	Substation # 831 Low Voltage Network
650 thru 651	480 V	Substation # 831 Low Voltage Network
652	480 V	Substation # 832 Low Voltage Network
653 thru 654	480 V	Substation # 819 Low Voltage Network
655 thru 657	480 V	Substation # 838 Low Voltage Network
658	208 V	Substation # 826 Low Voltage Network
659	480 V	Substation # 826 Low Voltage Network
660	480 V	Substation # 1054 Low Voltage Network
661 thru 663	480 V	Substation # 820 LCC Low Voltage Network
664	208 V	Substation # 820 LCC Low Voltage Network
665 thru 666	480 V	Substation # 820 LCC Low Voltage Network
667	208 V	Substation # 820 LCC Low Voltage Network
668 thru 678	480 V	Substation # 820 LCC Low Voltage Network
672	208 V	Substation # 820 LCC Low Voltage Network
673 thru 678	480 V	Substation # 821 LCC Low Voltage Network
679	208 V	Substation # 821 LCC Low Voltage Network
680	480 V	Substation # 882 Low Voltage Network

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
681		Not Used
682	480 V	Substation # 835
683	480 V	Substation # 836 Low Voltage Network
684		Not Used
685	480 V	Substation # 836 Low Voltage Network
686	480 V	Substation # 836 Low Voltage Network
687		Not Used
688	480 V	Substation # 836 Low Voltage Network
689 thru 691	480 V	Substation # 1052 Low Voltage Network
692	208 V	Substation # 1052 Low Voltage Network
693 thru 696	480 V	Substation # 1052 Low Voltage Network
697	480 V	Substation # 1052 Low Voltage Network
698 thru 701	480 V	Substation # 1052 Low Voltage Network
702 thru 704	480 V	Substation # 1032 Low Voltage Network
705		Not Used
706 thru 707	480 V	Substation # 1031 Low Voltage Network
708	208 V	Substation # 1031 Low Voltage Network
709	480 V	Substation # 1029 Low Voltage Network
710 thru 711	480 V	Substation # 1030 Low Voltage Network
712	208 V	Substation # 1030 Low Voltage Network
713	480 V	Substation # 1030 Low Voltage Network
714 thru 715	208 V	Substation # 1021 Low Voltage Network
716 thru 717		Not Used
718 thru 719	480 V	Substation # 1050 Low Voltage Network
720 thru 722	480 V	Substation # 1052 Low Voltage Network
723 thru 729		Not Used
730	480 V	Substation # 952 Low Voltage Network
731	480 V	Substation # 922 Low Voltage Network
732 thru 900		Not Used
901	13.8 Kv	LBS # 742 No Tie with LBS # 725
902	13.8 Kv	LBS # 928 ML Interface
903	13.8 Kv	LBS # 922 MSS Interface
904	13.8 Kv	Switching Station # 1002 - No-CB to ML Ind. Interface from Ind. Bus # 2
905	13.8 Kv	ML Power Interface Feeder from Switching Station # 1002 Instrumentation Bus

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
2026	13.8 Kv	Univ. Camera Pad # 12, 75 KVA Transformer
2098	13.8 Kv	Signal System Traffic, 15 KVA 1ø Transformer
2099	120/240 V	Signal System Traffic Transformer
2101	120/240 V	Consv. Stor H5-1571, 25 KVA 1ø Transformer
2102	13.8 Kv	Consv. HQ H5-1721, 50 KVA 1ø Transformer
2103	120/240 V	Consv. HQ H5-1721 Transformer
2104	13.8 Kv	Univ. Camera Pad # 13, 3 x 15 KVA Transformers
2105	208 V	Univ. Camera Pad # 13, 3 x 15 KVA Transformers
2106	13.8 Kv	54WT9-H4-1723, 10 KVA 1ø Transformer
2107	120/240 V	54WT9-H4-1723, 10 KVA 1ø Transformer
2108	13.8 Kv	Temp Guard Shack, 5 KVA 1ø Transformer
2109	120/240 V	Temp Guard Shack, 5 KVA 1ø Transformer
2110	13.8 Kv	Railroad Crossing, 10 KVA 1ø Transformer
2111	120/240 V	Railroad Crossing, 10 KVA 1ø Transformer
2112	13.8 Kv	Consv. Stor. H5-1571, 25 KVA 1ø Transformer
2113	13.68 Kv	Mosquito Control Pump, 3 x 37.5 KVA Transformers
2114	208 V	Mosquito Control Pump, 3 x 37.5 KVA Transformers
2115	13.8 Kv	Railroad Signal, 10 KVA 1ø Transformer
2116	120/240 V	Railroad Signal, 10 KVA 1ø Transformer
2117	13.8 Kv	Consv. Bldg. H5-1444, 15 KVA 1ø Transformer
2118	120/240 V	Consv. Bldg. H5-1444, 15 KVA 1ø Transformer
2119		Not Used
2120		Not Used
2121	13.8 Kv	H559, 3 x 15 KVA Transformers
2122	480 V	H559, 3 x 15 KVA Transformers
2123	13.8 Kv	H583, 25 KVA 1ø Transformer
2124	120/240 V	H583, 25 KVA 1ø Transformer
2125	13.8 Kv	Rec Area, 15 KVA 1ø Transformer
2126	120/240 V	Rec Area, 15 KVA 1ø Transformer
2127	13.68 Kv	Halouver Canal E4-2414, 3 x 25 KVA Transformers
2128	480 V	Halouver Canal E4-2414, 3 x 25 KVA Transformers
2129	13.8 Kv	54WT10, 10 KVA 1ø Transformer
2130	120/240 V	54WT10, 10 KVA 1ø Transformer

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
2131	13.8 Kv	LBS # 307 and Univ. Cam Pad # 4, 75 KVA Transformer
2132	208 V	Univ. Cam Pad # 4 Transformer
2133	13.8 Kv	LBS # 308 and Univ. Cam Pad # 7, 75 KVA Transformer
2134	208 V	Univ. Cam Pad # 7 Transformer
2135	13.8 Kv	LBS # 310
2136	208 V	Univ. Cam Pad # 12 Transformer
2137	13.8 Kv	W80, 3 x 15 KVA Transformers
2138	208 V	W80, 3 x 15 KVA Transformers
2139	13.8 Kv	Astro Beach House, 15 KVA 1Ø Transformer
2140	120/240 V	Astro Beach House, 15 KVA 1Ø Transformer
2141	13.8 Kv	W91-10 KVA 1Ø Transformer
2142	120/240 V	W91-10 KVA 1Ø Transformer
2143	13.8 Kv	Temp Gate # 6, 10 KVA 1Ø Transformer
2144	120/240 V	Temp Gate # 6, 10 KVA 1Ø Transformer
2145	13.8 Kv	N226, 10 KVA 1Ø Transformer
2146	120/240 V	N226, 10 KVA 1Ø Transformer
2147	13.8 Kv	Univ. Cam Pad # 5, 45 KVA Transformer
2148	208 V	Univ Cam Pad # 5, 45 KVA Transformer
2149	13.8 Kv	500WT1, 3 x 25 KVA Transformers
2150	208 V	500WT1, 3 x 25 KVA Transformers
2151	13.8 Kv	LBS # 304 and Univ Cam Pad # 16, 45 KVA Transformer
2152	208 V	Univ Cam Pad # 16 Transformer
2153	13.8 Kv	GGO-100, NO Switch to FPLCO
2154		Not Used
2155	13.8 Kv	G892-NC Fused Switch
2156	13.8 Kv	G883-NC Fused Switch
2157	13.8 Kv	G812
2158	13.8 Kv	G811-NC Fused Switch
2159	13.8 Kv	G802
2160	13.8 Kv	H501
2161	13.8 Kv	Wilson Recloser
2162	13.8 Kv	High Resolution Tracker # 1, 45 KVA
2163	13.8 Kv	LBS # 305
2164	13.8 Kv	N260
2165	13.8 Kv	Playlinda Sectionalizer
2166	13.8 Kv	LBS # 309
2167	13.8 Kv	W79
2168	13.8 Kv	W73IF-No-Fused Switch to CKAFS
2169	13.8 Kv	H504
2170 thru 2171	13.8 Kv	Industrial Area System
2172	13.8 Kv	54WT8, J6-1869, 15 KVA 1Ø Transformer

LAUNCHING COMPLEX

Bus Code	Voltage Level	Network Location
2173	120/240 V	54WT8, J6-1869, 15 KVA 1ø Transformer
2174 thru 2196		Industrial Area System
2197	13.8 Kv	FCA Mobile Site, 25 KVA 1ø Transformer
2198	120/240 V	FCA Mobile Site, 25 KVA 1ø Transformer
2199	13.8 Kv	Universal Cam Pad # 14, 45 KVA Transformer
2200	208 V	Universal Cam Pad # 14, 45 KVA Transformer
2201	13.8 Kv	Van Area, 112 1/2 KVA Transformer
2202	208 V	Van Area, 112 1/2 KVA Transformer
2203	208 V	High Resolution Tracker # 1 Transformer
2204	13.8 Kv	Weather Substation "B", 75 KVA Transformer
2205	208 V	Weather Substation "B", 75 KVA Transformer
2206 thru 2209	208 V	Industrial Area System
2210	13.8 Kv	LBS # 303
2211	13.8 Kv	LBS # 302
2212 thru 2914		Industrial Area System
2915	13.8 Kv	LBS # 301-No Switch to 3 x 167 KVA Voltage Regulators
2916	13.8 Kv	Fuse Switch on Tie between G 802 and H 501
2917	13.8 Kv	Tie between G 802 and H 501 Normally open

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
4	115 Kv	Orsino Substation - FPLCO Primary Loop
2008	13.2 Kv	Orsino Substation - Main Industrial Bus # 1
2009	13.2 Kv	Orsino Substation - Main Industrial Bus # 2
2010		Not Used
2011	13.2 Kv	Orsino Substation - Main Instrumentation Bus
2012	13.2 Kv	LBS # 54
2013	13.2 Kv	LBS # 9
2014	13.2 Kv	LBS # 45
2015	13.2 Kv	LBS # 22
2016	13.2 Kv	LBS # 1
2017	13.2 Kv	WYE on FD # 202 at MH 37
2018	13.2 Kv	WYE on FD # 203 at MH 37
2019	13.2 Kv	LBS # 56
2020	13.2 Kv	WYE on FD # 209 at MH 19
2021	13.2 Kv	LBS # 15
2022	13.2 Kv	WYE on FD # 205 at MH 38
2023	13.2 Kv	WYE on FD # 204 at MH 38
2024	13.2 Kv	LBS # 44
2025	13.2 Kv	LBS # 38
2026	13.2 Kv	Launching Complex System
2027	13.2 Kv	Substation CRB - NC Fuse Switch
2028	13.2 Kv	CKAFS Power Interface Switching Cubicle
2029	13.2 Kv	LBS # 55
2030	13.2 Kv	Visitors Information Center 750 KVA Transformer
2031	13.2 Kv	OCR Recloser
2032	13.2 Kv	LBS # 52
2033	13.2 Kv	LBS # 53
2034	13.2 Kv	LBS # 60, C1F M6-342 Primary Bus
2035	13.2 Kv	LBS # 4
2036	13.2 Kv	C1F Antenna Site Primary Bus
2037	13.2 Kv	LBS # 24
2038	13.2 Kv	RF Systems Test FAC, 750 KVA Transformer
2039	13.2 Kv	LBS # 25
2040	13.2 Kv	ECS # 1, 500 KVA Transformer
2041	13.2 Kv	ECS # 1, 500 KVA Transformer
2042	13.2 Kv	LBS # 26
2043	13.2 Kv	Fluid Test Support, 225 KVA Transformer
2044	13.2 Kv	Fluid Test Support, 500 KVA Transformer
2045	13.2 Kv	LBS # 27
2046	13.2 Kv	Hypergolic Test # 2, 750 KVA Transformer
2047	13.2 Kv	Hypergolic Test # 1, 500 KVA Transformer
2048	13.2 Kv	LBS # 28
2049	13.2 Kv	Cryogenic Test # 1, M7-1412, 150 KVA
2050	13.2 Kv	LBS # 34

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2051	13.2 Kv	LBS # 51
2052	13.2 Kv	Cryogenic Test # 2, M7-1410, 300 KVA Transformer
2053	13.2 Kv	OCR # 13-14 Recloser
2054	13.2 Kv	Ordnance Lab, M7-1417, 225 KVA Transformer
2055	13.2 Kv	LBS # 35
2056	13.2 Kv	Pyrotechnic Inst. M7-1469, 1000 KVA Transformer
2057	13.2 Kv	LBS # 57
2058	13.2 Kv	Ordnance Stor. Bldg. M7-1472, 150 KVA Transformer
2059	13.2 Kv	Reclosure By-Pass and East Repeater # 1, 3 x 25 KVA Transformers
2060	13.2 Kv	LBS # 2
2061	13.2 Kv	Central Supply Complex M6-698, 150 KVA Transformer
2062	13.2 Kv	Service Station, 15 KVA 1Ø Transformer
2063	13.2 Kv	LBS # 11
2064	13.2 Kv	Fire Station, 112 1/2 KVA Transformer
2065	13.2 Kv	LBS # 12
2066	13.2 Kv	Central Supply FAC M6-744, 300 KVA Transformer
2067	13.2 Kv	Central Supply Annex, 300 KVA Transformer
2068	13.2 Kv	Heat Plant M6-595, 300 KVA Transformer
2069	13.2 Kv	Sewage Plant Off, M6-895, 112 1/2 KVA Transformer
2070	13.2 Kv	LBS # 49
2071	13.2 Kv	LBS # 3
2072	13.2 Kv	Paint and Oil Stor. M6-894, 45 KVA Transformer
2073	13.2 Kv	Supply Whouse, M6-794, 300 KVA Transformer
2074	13.2 Kv	Comm. Main and Stor, M6-791, 300 KVA Transformer
2075	13.2 Kv	LBS # 46
2076	13.2 Kv	Auto Vehicle M6-688, 300 KVA Transformer
2077	13.2 Kv	Security Patrol, M6-589, 112 1/2 KVA Transformer
2078	13.2 Kv	LBS # 7
2079	13.2 Kv	LBS # 13
2080	13.2 Kv	LBS # 19
2081	13.2 Kv	WYE on FD # 202/203 at MH # 79
2082	13.2 Kv	WYE on FD # 202/203 at MH # 80
2083	13.2 Kv	LBS # 15-No Switch on FD # 212
2084	13.2 Kv	KSC Headquarters USS # 2D, 1500 KVA Transformer
2085	13.2 Kv	KSC Headquarters USS # 1B, 1500 KVA Transformer

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2086 thru 2091	13.2 Kv	Indian River System
2092	480 V	Unified S Band M5-1544, Utility Box
2093	13.2 Kv	Unified S Band, 500 KVA Transformer
2094	13.2 Kv	Unified S Band, 750 KVA Transformer
2095	480 V	Visitors Information Center Transformer
2096		Indian River System
2097	13.2 Kv	Primary Bus of Unified S Band Transformer
2100	13.2 Kv	Orsino Critical Bus
2098 thru 2169		Launching Complex System
2170	13.2 Kv	LBS # 48 and 54WT6-15 KVA 1ϕ Transformer
2171	120/240 V	54WT6, L6-75 Transformer
2172 thru 2173		Launching Complex System
2174	13.2 Kv	LBS # 36 and 54WT5-N6-2274, 15 KVA 1ϕ Transformer
2175	120/240 V	54WT5 Transformer
2176	13.2 Kv	LBS # 73 and Guard House 15 KVA 1ϕ Transformer
2177	120/240 V	Guard House Transformer
2178	13.2 Kv	LBS # 10 and South Repeat St 112 1/2 KVA Transformer
2179	208 V	Sewage Treatment Plant 45 KVA Transformer
2180	13.2 Kv	Cathodic Protection 15 KVA 1ϕ Transformer
2181	120/240 V	Cathodic Protection 15 KVA 1ϕ Transformer
2182	13.2 Kv	Reclamation Off, 15 KVA 1ϕ Transformer
2183	120/240 V	Reclamation Off, 15 KVA 1ϕ Transformer
2184	13.2 Kv	Reclamation Bldg. M6-1671, 37 1/2 KVA 1ϕ Transformer
2185	120/240 V	Reclamation Bldg. M6-1671, 37 1/2 KVA 1ϕ Transformer
2186	13.2 Kv	LBS # 50 and Universal Camera Pad # 18, 75 KVA Transformer
2187	208 V	Universal Camera Pad # 18 Transformer
2188	13.2 Kv	Frequency Control L5-683, 500 KVA Transformer
2189	480 V	Frequency Control L5-683, 500 KVA Transformer
2190	480 V	Traffic Control 75 KVA Transformer
2191	13.2 Kv	WYE on FD # 211 at MH 165 and Water Pump Station
2192	480 V	Water Pump Station 112 1/2 KVA Transformer
2193	13.2 Kv	Pass and I.D. Bldg. NC-1009 75 KVA Transformer
2194	208 V	Pass and I.D. Bldg. NC-1009 75 KVA Transformer

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2195	13.2 Kv	OCR-11-12 Recloser
2196	208 V	South Repeat Station 112 1/2 KVA Transformer
2197 thru 2205		Launching Complex System
2206 thru 2207		Not Used
2208	13.2 Kv	Sand Blasting FAC 3 x 50 KVA Transformers
2209	480 V	Sand Blasting FAC MG-1622 Transformer
2210 thru 2211		Launching Complex System
2212 thru 2213		Not Used
2214	13.2/13.8 Kv	3 x 167 KVA Voltage Regulators Industrial Area-Launching Complex Interface
2215	13.2 Kv	LBS # 47
2216	13.2 Kv	P8 Fused Switch
2217	13.2 Kv	Sewage Treatment Plant 45 KVA Transformer
2218	13.2 Kv	LBS # 43 and Univ Cam Pad # 15, 75 KVA Transformer
2219	208 V	Univ Cam Pad # 15 Transformer
2220	13.2 Kv	54WT1, L7-988, 3 x 37 1/2 KVA Transformers
2221	480 V	54 WT1, L7-988, 3 x 37 1/2 KVA Transformers
2222	13.2 Kv	FCA Mobile Site 1, L7-2242, 25 KVA 1ø Transformer
2223	120/240 V	FCA Mobile Site1, L7-2242, 25 KVA 1ø Transformer
2224	13.2 Kv	LBS # 40
2225	120/240 V	54WT2, M7-335, 15 KVA 1ø Transformer
2226	208 V	Universal Cam Pad # 2, 75 KVA Transformer
2227	208 V	East Repeater # 1, 3 x 25 KVA Transformers
2228	13.2 Kv	News Center 500 KVA Transformer
2229	208 V	News Center Transformer
2230	13.2 Kv	WYE on FD # 208 and Primary Bus Supply and GSE Service
2231	480 V	Supply and GSE Service Transformer # 2A
2232	480 V	Supply and GSE Service Transformer # 1A
2233	13.2 Kv	WYE on FD # 208 and Primary Bus Supply Shipping West
2234	208 V	Supply,Shipping West Transformer # 2
2235	480 V	Supply,Shipping West Transformer # 1
2236	13.2 Kv	Flight Crew Training 1000 KVA Transformer SS-B
2237	13.2 Kv	Flight Crew Training SS-C and A Transformers

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2238	480 V	Flight Crew Training SS-A Transformer (1500 KVA)
2239	208 V	Flight Crew Training Transformer SS-B (1000 KVA)
2240	480 V	Flight Crew Training SS-C Transformer (750 KVA)
2241	13.2 Kv	WYE on FD # 208 and Orsino Bridge (East) 112 1/2 KVA Transformer
2242	480 V	Orsino Bridge (East) M7-1150 Transformer
2243	13.2 Kv	LBS # 23
2244	13.2 Kv	LBS # 20
2245	13.2 Kv	LBS # 17
2246	13.2 Kv	LBS # 21
2247	13.2 Kv	LBS # 39
2248	13.2 Kv	LBS # 41
2249	13.2 Kv	LBS # 42
2250	480 V	Fluid Test Support Transformer # 2 (500 KVA)
2251	480 V	Fluid Test Support Transformer # 1 (225 KVA)
2252	480 V	ECS # 1 Transformer # 1 (500 KVA)
2253	480 V	ECS # 1 Transformer # 2 (500 KVA)
2254	480 V	RF Systems Test FAC Transformer
2255	480 V	Hypergolic Test # 2 Transformer
2256	480 V	Hypergolic Test # 1 Transformer
2257	480 V	Cryogenic Test # 2 Transformer
2258	480 V	Ordnance Lab Transformer
2259	480 V	Pyrotechnic Instal Transformer
2260	208 V	Ordnance Storage Transformer
2261	480 V	Sewage Plant Off Transformer
2262	208 V	Paint and Oil Storage Transformer
2263	480 V	Supply Warehouse Transformer
2264	480 V	Comm Maint and Stor. Transformer
2265	208 V	Auto Vehicle Maint.
2266	208 V	Security Patrol
2267	13.2 Kv	LBS # 70
2268	480 V	Generator # 1 300 KVA Transformer
2269	480 V	Generator Substation 750 KVA Transformer
2270	480 V	CIF M6-342, 500 KVA Transformer
2271	2.4 Kv	Chillers # 1 and # 2 at CIF
2272	13.2 Kv	CIF 1500 KVA Transformer # 8
2273	2.4 Kv	CIF 1500 KVA Transformer # 8
2274	2.4 Kv	CIF 1500 KVA Transformer # 7
2275	480 V	CIF 2000 KVA Transformer # 6
2276	208 V	CIF 1000 KVA Transformer # 5
2277	208 V	CIF 1000 KVA Transformer # 4

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2278	13.2 Kv	LBS # 69 and Primary Bus FD # 102 at C1F
2279	13.2 Kv	LBS # 69 and Primary Bus FD # 103 at C1F
2280	13.2 Kv	LBS # 71 N.C. Switch
2281	13.2 Kv	C1F 1000 KVA Transformer # 3
2282	208 V	C1F 1000 KVA Transformer # 3
2283	13.2 Kv	C1F 1000 KVA Transformer # 2
2284	208 V	C1F 1000 KVA Transformer # 2
2285	13.2 Kv	C1F 1000 KVA Transformer # 1
2286	208 V	C1F 1000 KVA Transformer # 1
2287	13.2 Kv	LBS # 5
2288	13.2 Kv	LBS # 72
2289	2.4 Kv	Chiller # 3 at C1F
2290	2.4 Kv	Chillers # 1 and # 2 Starters
2291	2.4 Kv	Substation "OA" Bus
2292	480 V	Substation "OB" 1000 KVA Transformer
2293	13.2 Kv	FD # 202 Primary Bus at Substation "OA"

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2294	13.2 Kv	Primary Bus FD # 204 at Substation "OA"
2295	13.2 Kv	Substation "OA" 2000 KVA Transformer West
2296	13.2 Kv	Substation "OA" 2000 KVA Transformer East
2297	2.4 Kv	Substation "OA" 2000 KVA Transformer East
2298	2.4 Kv	Substation "OA" Transformer West
2299	13.2 Kv	Substation "WJ" 500 KVA Transformer
2300	208 V	Substation "WJ" 500 KVA Transformer
2301	13.2 Kv	Substation "WL" 750 KVA Transformer
2302	480 V	Substation "WL" 750 KVA Transformer
2303	13.2 Kv	Substation "WK" 500 KVA Transformer
2304	208 V	Substation "WK" 500 KVA Transformer
2305	13.2 Kv	Substation "WH" 225 KVA Transformer
2306	208 V	Substation "WH" 225 KVA Transformer
2307	13.2 Kv	Substation "WG" 500 KVA Transformer
2308	480 V	Substation "WG" 500 KVA Transformer
2309	13.2 Kv	Substation "EA" 150 KVA Transformer
2310	208 V	Substation "EA" 150 KVA Transformer
2311	13.2 Kv	Substation "EB" 150 KVA Transformer
2312	208 V	Substation "EB" 150 KVA Transformer
2313	13.2 Kv	Substation "ED" 150 KVA Transformer
2314	208 V	Substation "ED" 150 KVA Transformer
2315	13.2 Kv	Substation "EC" 300 KVA Transformer
2316	480 V	Substation "EC" 300 KVA Transformer
2317	13.2 Kv	Substation "OY" 750 KVA Transformer
2318	480 V	Substation "OY" 750 KVA Transformer
2319	13.2 Kv	Substation "EE" 500 KVA Transformer
2320	480 V	Substation "EE" 500 KVA Transformer
2321	13.2 Kv	Substation "OZ" 500 KVA Transformer
2322	208 V	Substation "OZ" 500 KVA Transformer
2323	13.2 Kv	Substation "WA" 300 KVA Transformer
2324	208 V	Substation "WA" 300 KVA Transformer
2325	13.2 Kv	Substation "WB" 300 KVA Transformer
2326	208 V	Substation "WB" 300 KVA Transformer
2327	13.2 Kv	Substation "WC" 300 KVA Transformer
2328	480 V	Substation "WC" 300 KVA Transformer
2329	13.2 Kv	Substation "WD" 300 KVA Transformer
2330	208 V	Substation "WD" 300 KVA Transformer
2331	13.2 Kv	Substation "WE" 500 KVA Transformer
2332	208 V	Substation "WE" 500 KVA Transformer
2333	13.2 Kv	Substation "WF" 500 KVA Transformer
2334	208 V	Substation "WF" 500 KVA Transformer
2335	13.2 Kv	Primary Bus FD # 202-8 at Substation "W..."
2336	13.2 Kv	Primary Bus FD # 204-6 at Substation "W..."

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2337	13.2 Kv	Primary Bus FD # 202-8 at Substation "W..."
2338	13.2 Kv	Primary Bus FD # 202-8 at Substation "W..."
2339	13.2 Kv	Primary Bus FD # 204-6 at Substation "W..."
2340	13.2 Kv	WYE on FD # 204-6 at MH 83
2341	13.2 Kv	WYE on FD # 202-8 at MH 83
2342	13.2 Kv	Substation "EE" FD # 204-6 N.C.
2343	13.2 Kv	Substation "EE" FD # 202-8 N.O.
2344	13.2 Kv	LBS # 58
2345	13.2 Kv	LBS # 57
2346	13.2 Kv	Primary Bus FD # 202-8 "E..."
2347	13.2 Kv	Primary Bus FD # 204-6
2348	13.2 Kv	Primary Bus FD # 204-6 at CB Station
2349	13.2 Kv	Substation "OA" Primary Bus FD # 202-8 and # 202-7
2350	2.4 Kv	Chiller # 102 at Substation "OA"
2351	2.4 Kv	Chiller # 103 at Substation "OA"
2352	2.4 Kv	Chiller # 101 at Substation "OA"
2353	13.2 Kv	Substation "Z" 300 KVA Transformer
2354	208 V	Substation "Z" 300 KVA Transformer
2355	13.2 Kv	Substation "Y" 300 KVA Transformer
2356	480 V	Substation "Y" 300 KVA Transformer
2357	13.2 Kv	Substation "V" 300 KVA Transformer
2358	208 V	Substation "V" 300 KVA Transformer
2359	13.2 Kv	Substation "X" 300 KVA Transformer
2360	208 V	Substation "X" 300 KVA Transformer
2361	13.2 Kv	Substation "W" 300 KVA Transformer
2362	208 V	Substation "W" 300 KVA Transformer
2363	13.2 Kv	Substation "U" 300 KVA Transformer
2364	208 V	Substation "U" 300 KVA Transformer
2365	13.2 Kv	Substation "T" 300 KVA Transformer
2366	208 V	Substation "T" 300 KVA Transformer
2367	13.2 Kv	Substation "S" 300 KVA Transformer
2368	208 V	Substation "S" 300 KVA Transformer
2369	13.2 Kv	Substation "R" 500 KVA Transformer
2370	480 V	Substation "R" 500 KVA Transformer
2371	13.2 Kv	Substation "Q" 300 KVA Transformer
2372	208 V	Substation "Q" 300 KVA Transformer
2373	13.2 Kv	Substation "AA" 300 KVA Transformer
2374	208 V	Substation "AA" 300 KVA Transformer
2375	13.2 Kv	Substation "P" 300 KVA Transformer
2376	208 V	Substation "P" 300 KVA Transformer
2377	13.2 Kv	Substation "N" 300 KVA Transformer
2378	480 V	Substation "N" 300 KVA Transformer
2379	13.2 Kv	Substation "M" 300 KVA Transformer
2380	208 V	Substation "M" 300 KVA Transformer
2381	13.2 Kv	Substation "L" 300 KVA Transformer

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2382	208 V	Substation "L" 300 KVA Transformer
2383	13.2 Kv	Substation "K" 300 KVA Transformer
2384	208 V	Substation "K" 300 KVA Transformer
2385	13.2 Kv	Substation "J" 300 KVA Transformer
2386	208 V	Substation "J" 300 KVA Transformer
2387	13.2 Kv	Substation "H" 500 KVA Transformer
2388	480 V	Substation "H" 500 KVA Transformer
2389	13.2 Kv	Substation "G" 300 KVA Transformer
2390	208 V	Substation "G" 300 KVA Transformer
2391	13.2 Kv	WYE on FD # 203 at LBS # 30
2392	13.2 Kv	LBS # 30
2393	13.2 Kv	Primary Bus FD # 203-3 at Substation "G" and "Z"
2394	13.2 Kv	Primary Bus FD # 203-1 at Substation "F"
2395	13.2 Kv	LBS # 18
2396	13.2 Kv	WYE on FD # 204 at MH 64
2397	13.2 Kv	Primary Bus FD # 205-4 at Substation "G" and "Z"
2398	13.2 Kv	Primary Bus FD # 205-4 at Substation "H" and "J"
2399	13.2 Kv	Primary Bus FD # 203-3 at Substation "H" and "J"
2400	13.2 Kv	LBS # 67
2401	13.2 Kv	LBS # 68
2402	13.2 Kv	Primary Bus FD # 205-4 at Substation "AA"
2403	13.2 Kv	Primary Bus FD # 205-4 at Substation "V"
2404	13.2 Kv	Primary Bus FD # 205-4 at Substation "M"
2405	13.2 Kv	Primary Bus FD # 203-3 at Substation "V"
2406	13.2 Kv	Primary Bus FD # 203-3 at Substation "M"
2407	13.2 Kv	Primary Bus FD # 205-4 at Substation "K"
2408	13.2 Kv	Primary Bus FD # 203-3 at Substation "K"
2409	13.2 Kv	Primary Bus FD # 205-4 at Substation "L"
2410	13.2 Kv	Primary Bus FD # 203-3 at Substation "L"
2411	13.2 Kv	Primary Bus FD # 205-4 at Substation "N"
2412	13.2 Kv	Primary Bus FD # 203-3 at Substation "N"

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2413	13.2 Kv	Primary Bus FD # 205-4 at Substation "P"
2414	13.2 Kv	Primary Bus FD # 203-3 at Substation "P"
2415	13.2 Kv	Primary Bus FD # 205-4 at Substation "T"
2416	13.2 Kv	Primary Bus FD # 203-3 at Substation "T"
2417	13.2 Kv	Primary Bus FD # 203-3 at Substation "S"
2418	13.2 Kv	Primary Bus FD # 205-4 at Substation "S"
2419	13.2 Kv	Primary Bus FD # 203-3 at Substation "R"
2420	13.2 Kv	Primary Bus FD # 205-4 at Substation "R"
2421	13.2 Kv	Primary Bus FD # 205-4 at Substation "Q"
2422	13.2 Kv	Primary Bus FD # 203-3 at Substation "Q"
2423	13.2 Kv	Primary Bus FD # 203-3 at Substation "W"
2424	13.2 Kv	Primary Bus FD # 205-4 at Substation "W"
2425	13.2 Kv	Primary Bus FD # 203-3 at Substation "X"
2426	13.2 Kv	Primary Bus FD # 205-4 at Substation "X"
2427	13.2 Kv	Primary Bus FD # 203-3 at Substation "Y"
2428	13.2 Kv	Primary Bus FD # 205-4 at Substation "Y"
2429	13.2 Kv	Primary Bus FD # 203-3 at Substation "U"
2430	13.2 Kv	Primary Bus FD # 205-4 at Substation "U"
2431	13.2 Kv	Base OPS 300 KVA Transformer
2432	480 V	Base OPS 300 KVA Transformer
2433	13.2 Kv	Base Support 225 KVA Transformer
2434	208 V	Base Support 225 KVA Transformer
2435	13.2 Kv	Base Support 500 KVA Transformer
2436	480 V	Base Support 500 KVA Transformer
2437	13.2 Kv	Electro Mag Lab 150 KVA Transformer
2438	208 V	Electro Mag Lab 150 KVA Transformer
2439	13.2 Kv	So. Bell Exchange 500 KVA Transformer
2440	208 V	So. Bell Exchange 500 KVA Transformer
2441	13.2 Kv	Central Tel Off 500 KVA Transformer
2442	208 V	Central Tel Off 500 KVA Transformer

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2443	13.2 Kv	Central Tel Off 750 KVA Transformer
2444	480 V	Central Tel Off 750 KVA Transformer
2445	13.2 Kv	Cafeteria 500 KVA Transformer
2446	208 V	Cafeteria 500 KVA Transformer
2447	13.2 Kv	Dispensary 112 1/2 KVA Transformer
2448	208 V	Dispensary 112 1/2 KVA Transformer
2449	120/240 V	Dispensary X Ray 15 KVA 1Ø Transformer
2450	480 V	Heat Plant 300 KVA Transformer
2451	480 V	Central Supply Annex 300 KVA Transformer
2452	480 V	Central Supply FAC 300 KVA Transformer
2453	208 V	Fire Station 112 1/2 KVA Transformer
2454	480 V	Central Supply Complex 150 KVA Transformer
2455	120/240 V	Service Station 15 KVA 1Ø Transformer
2456	13.2 Kv	LBS # 6
2457	13.2 Kv	WYE on FD # 208-5 in MH 36
2458	13.2 Kv	WYE on FD # 208-6-7 in MH 30
2459	13.2 Kv	NO Switch for FD # 208-5 at LBS # 8
2460	13.2 Kv	LBS # 8
2461	13.2 Kv	NC Switch for FD # 209-4-8 at LBS # 8
2462	13.2 Kv	WYE on FD # 209 at MH 22
2463	13.2 Kv	Auditorium 225 KVA Transformer
2464	208 V	Auditorium 225 KVA Transformer
2465	13.2 Kv	Substation "F" 500 KVA Transformer
2466	480 V	Substation "F" 500 KVA Transformer
2467	13.2 Kv	Substation "E" 1000 KVA Transformer
2468	480 V	Substation "E" 1000 KVA Transformer
2469	13.2 Kv	Substation "D" 500 KVA Transformer
2470	480 V	Substation "D" 500 KVA Transformer
2471	13.2 Kv	Substation "C" 1500 KVA Transformer
2472	2.4 Kv	Substation "C" 1500 KVA Transformer
2473	13.2 Kv	Substation "B" 1500 KVA Transformer
2474	2.4 Kv	Substation "B" 1500 KVA Transformer
2475	13.2 Kv	Substation "A" 500 KVA Transformer
2476	480 V	Substation "A" 500 KVA Transformer
2477	480 V	KSC Headquarters USS # 1B, 2500 KVA Transformer
2478	13.2 Kv	KSC Headquarters USS # 2C, 1500 KVA Transformer
2479	480 V	KSC Headquarters USS # 2C, 1500 KVA Transformer
2480	480 V	KSC Headquarters USS # 2D, 1500 KVA
2481	13.2 Kv	KSC Headquarters USS # 1A, 2500 KVA Transformer
2482	480 V	KSC Headquarters USS # 1A, 2500 KVA Transformer
2483	13.2 Kv	WYE on FD # 205 at MH 82
2482	13.2 Kv	WYE on FD # 205 at MH 80

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2485	13.2 Kv	LBS # 14
2486	13.2 Kv	WYE on FD # 204 at MH 39
2487	13.2 Kv	WYE on FD # 205 at MH 39
2488	13.2 Kv	LBS # 16
2489	13.2 Kv	LBS # 64
2490	13.2 Kv	LBS # 65 and # 60
2491	13.2 Kv	NC Switch on FD # 10 at Substation "B" and "C"
2492	13.2 Kv	NC Switch FD # 12 at Substation "A"
2493	13.2 Kv	NO Switch on FD # 9 at Substation "B" and "C"
2494	13.2 Kv	NC Switch on FD # 11 at Substation "A"
2495		Not Used
2496	2.4 Kv	Chiller # 1 at Substation "B"
2497	2.4 Kv	Chiller # 2 at Substation "B"
2498		Not Used
2499	2.4 Kv	Chiller # 3 at Substation "C"
2500	2.4 Kv	Chiller # 4 at Substation "C"
2501	13.2 Kv	LBS # 33 FDR # 2
2502	13.2 Kv	FD # 2 at Substation "D"
2503	13.2 Kv	FD # 1 at Substation "D"
2504	13.2 Kv	Substation "CRC" 300 KVA Transformer
2505	208 V	Substation "CRC" 300 KVA Transformer
2506	13.2 Kv	Substation "CRB" 300 KVA Transformer
2507	208 V	Substation "CRB" 300 KVA Transformer
2508	13.2 Kv	Substation "CRA" 300 KVA Transformer
2509	208 V	Substation "CRA" 300 KVA Transformer
2510	13.2 Kv	Substation "CRD" 500 KVA Transformer
2511	208 V	Substation "CRD" 500 KVA Transformer
2512	480 V	ClF Antenna Site 3 - 750 KVA Transformer
2513	208 V	ClF Antenna Site 1 - 300 KVA Transformer
2514	13.2 Kv	LBS # 62
2515	208 V	ClF Antenna Site 2 - 225 KVA Transformer
2516	13.2 Kv	FD # 103 at ClF Antenna Site # 1
2517	13.2 Kv	ClF Antenna Site 1 - 300 KVA Transformer
2518	13.2 Kv	WYE on FD # 102-4 at MH 65
2519	13.2 Kv	FD # 102 N.O. at Substation "CRB"
2520	13.2 Kv	FD # 102 N.O. at Substation "CRD"
2521	13.2 Kv	FD # 101 NC at Substation "CRA"
2522	13.2 Kv	FD # 101 NC at Substation "CRD"
2523	13.2 Kv	FD # 102 NO at Substation "CRA"
2524	13.2 Kv	Tel 4, N6-229E, 225 KVA Transformer

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2525	208 V	Tel 4, N6-229E, 225 KVA Transformer
2526	13.2 Kv	Central Telemetry 750 KVA Transformer
2527	208 V	Central Telemetry 750 KVA Transformer
2528	13.2 Kv	Central Telemetry 750 KVA Transformer
2529	208 V	Central Telemetry 750 KVA Transformer
2530	13.2 Kv	TPQ-18, Q6-82, 300 KVA Transformer
2531	480 V	TPQ-18, Q6-82, 300 KVA Transformer
2532	13.2 Kv	TPQ-18, Q6-82, 300 KVA Transformer
2533	480 V	TPQ-18, Q6-82, 300 KVA Transformer
2534	13.2 Kv	Universal Camera Pad # 1, 75 KVA Transformer
2535	208 V	Universal Camera Pad # 1, 75 KVA Transformer
2536	13.2 Kv	LBS # 37
2537	13.2 Kv	WYE on FD # 211 at MH 235
2538	13.2 Kv	LBS # 38 FD # 211
2539	13.2 Kv	Central Telemetry 1000 KVA Transformer
2540	13.2 Kv	LBS # 38 N.C. Switch
2541	13.2 Kv	LBS # 38 N.C. Switch
2542 thru 2544	480 V	Substation "A" Low Voltage Network
2545	480 V	O and C Cooling Tower Pump # 1 - 100 HP
2546	480 V	O and C Cooling Tower Pump # 2 - 100 HP
2547		Not Used
2548	480 V	Substation "A" Low Voltage Network
2549	480 V	Chilled Water Pump # 3 - 75 HP
2550	480 V	Chilled Water Pump # 2 - 75 HP
2551 thru 2553	480 V	Substation "D" Low Voltage Network
2554 thru 2568	480 V	Substation "E" Low Voltage Network
2569 thru 2574	480 V	Substation "F" Low Voltage Network
2575 thru 2582	480 V	Substation "H" Low Voltage Network
2583 thru 2594	480 V	Substation "N" Low Voltage Network
2595 thru 2602	480 V	Substation "R" Low Voltage Network
2603 thru 2605	480 V	Substation "Y" Low Voltage Network
2606 thru 2609	480 V	Substation "EC" Low Voltage Network
2610 thru 2613	480 V	Substation "EE" Low Voltage Network
2614 thru 2622	480 V	Substation "OB" Low Voltage Network
2623 thru 2626	480 V	Substation "OY" Low Voltage Network
2627 thru 2633	480 V	Substation "WC" Low Voltage Network
2634 thru 2638	480 V	Substation "WG" Low Voltage Network
2639 thru 2649	480 V	Substation "WL" Low Voltage Network
2650 thru 2658	480 V	Flight Crew Training Substation "A"
2659 thru 2664	480 V	Flight Crew Training Substation "C"
2665 thru 2676	480 V	CIF Power Center # 6
2677 thru 2683	480 V	CIF Antenna Substation # 3
2684 thru 2685	480 V	Spacecraft Spares Bldg. M7-505 Substation "A"
2686 thru 2687	480 V	Spacecraft Spares Bldg. M7-505 Substation "B"

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2688 thru 2689	480 V	Spacecraft Spares Bldg. M7-505 Substation "D"
2690	480 V	Central Supply WHouse Bldg. M7-698
2691 thru 2694	480 V	Central Supply WHouse Bldg. M6-744
2695	480 V	Central Supply WHouse Bldg. M6-791
2696	480 V	Central Supply WHouse Bldg. M6-794
2697 thru 2710	480 V	KSC Headquarters Substation # 1
2711 thru 2729	480 V	KSC Headquarters Substation # 2
2730 thru 2733	480 V	KSC Headquarters Substation # 1
2734	480 V	KSC Headquarters Substation # 2
2735	480 V	Sewage Treatment Plant
2736 thru 2739	480 V	Base Support M6-486
2740 thru 2741	480 V	Heat Plant
2742 thru 2748	480 V	TPQ-18 (Q6-82)
2749	480 V	So. Bell Exchange
2750 thru 2765	480 V	Central Tel Bldg. N6-2296
2766 thru 2771	480 V	Bldg. M6-138 C.D. and S.C.
2772	480 V	Unified S Band Technical Bus
2773 thru 2785	480 V	Unified S Band Bldg. M5-1444
2786 thru 2790	480 V	Visitors Information Center
2791	480 V	Frequency Control Analysis
2792 thru 2798	480 V	ECS Bldg.
2799 thru 2804	480 V	Fluid Test Support
2805 thru 2809	480 V	RF System Test FAC
2810	480 V	Cryogenic Test # 1
2811 thru 2815	480 V	Cryogenic Test # 2
2816 thru 2823	480 V	Hypergolic Test # 1
2824 thru 2836	480 V	SAEF # 2 Bldg. M7-1210
2837	480 V	Ordnance Lab
2838 thru 2850	480 V	SAEF # 1 Bldg. M7-1469
2851	480 V	Ordnance Stor. Bldg. M7-1472

INDUSTRIAL AREA

Bus Code	Voltage Level	Network Location
2850		
2851		
2852	13.2 Kv	Pump Station, M7-1098, 112 1/2 KVA Transformer
2853	480 V	Pump Station, M7-1098, 112 1/2 KVA Transformer
2854 thru 2900		Not Used
2901	13.2 Kv	LBS # 6 NO Switch FD # 208
2902	13.2 Kv	LBS # 2 NO Switch FD # 209
2903	13.2 Kv	LBS # 45 NO Switch FD # 207
2904	13.2 Kv	LBS # 62 NO Switch FD # 103
2905	13.2 Kv	FD # 103 NC Switch to Substation "CRC"
2906	13.2 Kv	LBS # 18 NO Switch FD # 205
2907	13.2 Kv	LBS # 18 NO Switch FD # 202
2908	13.2 Kv	LBS # 19 NO Switch FD # 203
2909	13.2 Kv	LBS # 58 NO Switch FD # 202-8
2910	13.2 Kv	LBS # 13 NO Switch FD # 202
2911	13.2 Kv	LBS # 15 NO Switch FD # 202/203
2912	13.2 Kv	LBS # 14 NO Switch FD # 204
2913	13.2 Kv	LBS # 16 NO Switch FD # 204
2914	13.2 Kv	LBS # 47 NC Switch to Volt Regulators
2915		Launching Complex System
2916		Launching Complex System
2917		Launching Complex System

INDIAN RIVER BRIDGE SYSTEM

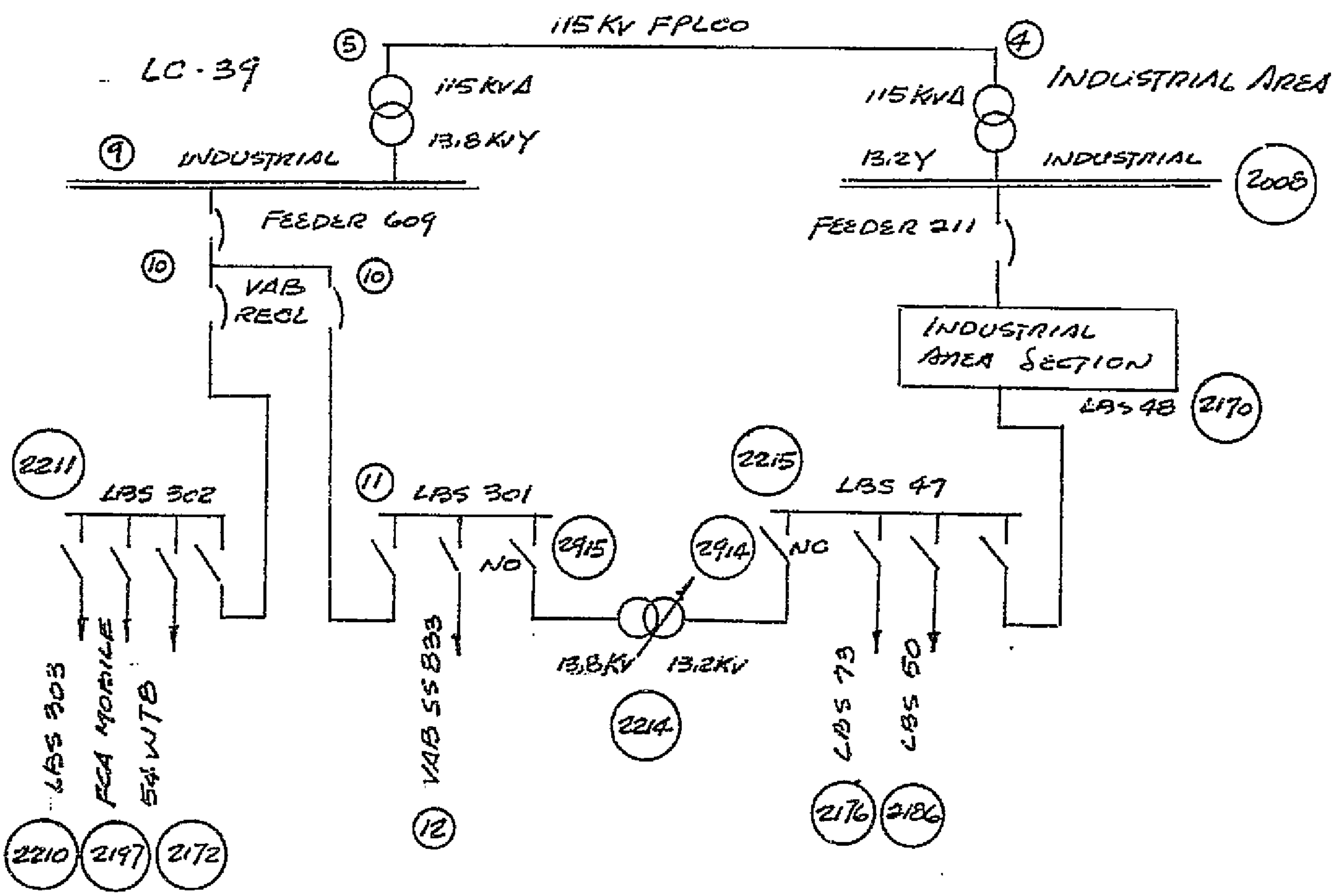
Bus Code	Voltage Level	Network Location
2086	13.2 Kv	F30, 3 x 37 1/2 KVA Transformers
2087	480 V	F30, 3 x 37 1/2 KVA Transformers
2088	13.2 Kv	Pass I.D. Gate # 3, 3 x 25 KVA Transformers
2089	208 V	Pass I.D. Gate # 3, 3 x 25 KVA Transformers
2090	208 V	NASA TWA Tours 3 x 25 KVA Transformers
2091	13.2 Kv	NASA TWA Tours 3 x 25 KVA Transformers
2096	13.2 Kv	Reclosure and By-Pass

B. Launching Complex - Industrial Area Systems Interconnection:

a) Network Section connected to Launching Complex VAB Feeder # 609 (operational voltage 13.8 Kv) or to Industrial Area Feeder # 211 (operational voltage 13.2 Kv) through 3 x 167 KVA voltage regulators 13.2/13.8 Kv.

This network section has been coded 2000, belonging to the Industrial Area Network, but has been considered connected to the Launching Complex System in the short circuit program.

A single line diagram of the existing interconnection between the Launching Complex and the Industrial Area Systems with the code numbers included follows:



Section considered normally connected to Launch Complex

Section considered normally connected to Industrial Area

Line	Code F	Status
VAB Recloser	10	Closed
VAB Recloser to LBS 301	10-11	Closed
LBS 301 to voltage regulators	2915	Open
LBS 301 to substation ≠ 833	11-12	Closed
VAB Recloser to LBS 302	10-2211	Closed
LBS 302 to LBS 303	2211-2210	Closed
LBS 302 to FCA Mobile site	2211-2197	Closed
LBS 302 to 54WT8	2211-2172	Closed

The network section of the Industrial Area that has been considered normally connected to the Launch Complex Feeder VAB 609 has the following primary bus codes:

13.8 Kv:

2026, 2098, 2102, 2104, 2106, 2108, 2110, 2115, 2117, 2119, 2121, 2123, 2125, 2129, 2131, 2133, 2137, 2139, 2141, 2143, 2147, 2149, 2151, 2153 thru 2169, 2172, 2197, 2199, 2210, 2211, 2915, 2135, 2201, 2204

13.68 Kv:

2113, 2127, 2145

The following lines will appear in the Launching Complex short circuit program:

Bus Code	Positive-Negative Sequence	Zero Sequence
Source-5	.00139 + j.00753	Infinite
5-9	.0 + j.081	.0 + j.081
5-9	.0 + j.081	.0 + j.081
5-9	.0 + j.081	.0 + j.081
5-9	.0 + j.081	.0 + j.081
9-10	.001041 + j.0005617	.0061526 + j.00459
10-11	.0005835 + j.000315	.00345 + j.002574
11-12	.001183 + j.000639	.006996 + j.005219
10-2211	.034675 + j.017164	.0767351 + j.048637
2211-2210	.011762 + j.0057188	.024154 + j.0142781

Plus all the primary lines and associated secondary lines where bus code numbers are listed above in the 13.8 Kv or 13.68 Kv sections.

Line 11-2915 will not appear in either the Launching Complex or Industrial Area short circuit programs because it is a normally open condition.

b) If user wants to incorporate the above network section into the Industrial Area short circuit program, the following steps shall be taken:

....

1. Incorporate all lines coded at the 2000 level formerly in the Launching Complex short circuit program.

2. Incorporate also lines 10-11, 11-12, and 10-2211.

3. Add the following new lines:

Bus Code	Positive-Negative Sequence	Zero Sequence
2915-11	Infinite	Infinite
Source-11	$R_1 + jX_1$	$R_o + jX_o$

Where

$R_1 + jX_1$ = resistance and reactance to positive sequence of bus code 2915 as given by 3 ø symmetrical short-circuit program of the Industrial Area

$R_o + jX_o$ = resistance and reactance to zero sequence of bus code 2915 obtained from the line to ground fault short circuit program as follows:

Consider R + jX is the equivalent resistance and reactance component of the impedance corresponding to bus code 2915 given by the line to ground fault short circuit program for the Industrial Area

$$R + jX = (R_1 + R_2 + R_o) + j\ (X_1 + X_2 + X_o)$$

Where $R_2 + jX_2$ is the impedance of bus 2915 to negative sequence

But in the average $R_1 \approx R_2$, $X_1 \approx X_2$

Then

$$R_o = R - 2R_1$$
$$X_o = X - 2X_1$$

In this step, line source-11 = impedance of bus code 2915 establishes a Thevenin equivalent impedance at bus 11 (LBS 301) looking from 2915 towards the Industrial Area network, and is equal to by-pass the whole Industrial Area network from Industrial bus (code # 8) to LBS 301 (bus code # 2915). Line 2915-11 will open LBS 301 (2915) from the Industrial Area network.

The above step is valid whatever the configuration of the Industrial Area network is up to bus code 2915.

4. Multiply impedances to all sequences of all lines considered in steps 1, 2, and 3 above by the factor:

$$\left(\frac{13.2}{13.8}\right)^2 = .9149338$$

5. Source voltage to be $(\frac{13.2}{13.8})^2$ = .9149338, or the same source voltage as the Industrial Area.

Steps 4 and 5 will incorporate the network section into the Industrial Area network. Step 3 takes into account the voltage regulators input from Feeder # 211 from the Industrial Area at 13.2 Kv level and the voltage regulators output of 13.8 Kv to the network section. This is accomplished multiplying the impedance of the network section by the .9149338 factor which is equal to increase the voltage to 1.0 = 13.8 Kv; this way we can use the same voltage source as the rest of the Industrial Area.

c) If user wants to feed part of the normal Industrial Area network from the Launching Complex Feeder VAB # 609 through the 3 x 167 KVA voltage regulators 13.8/13.2 Kv, the following steps will be required:

1. Open the Industrial Area network at the desired switching station with a line card of infinite impedance. If a new bus code is required, it is suggested to use code numbers at the 2900 level.

2. Multiply all sequence impedances of all lines in the Industrial Area to be connected to the Launching Complex VAB Feeder # 609 by the factor $(\frac{13.8}{13.2})^2$ = 1.0454545.

This will take into consideration the 13.8/13.2 Kv voltage regulators' effect and maintain a source of 1.0 = 13.8 Kv for the whole network.

3. Introduce a new line:

Bus Code	Positive-Negative Sequence	Zero Sequence
11-2915	.0 + j.0	.0 + j.0

The desired network section is connected to the Launching Complex network.

III. Short Circuit Program

1. Introduction

The KSC short circuit program is described in detail in the following paragraphs. The approach taken is to describe first the basic computational procedures and then the details of program structure. Emphasis is placed on program utilization and procedures to update the program in accordance with subsequent network changes and additions.

The short circuit program is configured to compute both three phase and single phase fault conditions. Line open computation options also are provided. The computational procedures utilized are based on essentially standard techniques employed in power industry short circuit programs. Network impedance matrix formation algorithms and short circuit algorithms are based upon those given in the book "Computer Methods in Power System Analysis" by Stagg and El-Abiad. Specific algorithms used are given in subsequent paragraphs. The program is specifically tailored to the KSC network and utilizes the radial structure of the network to reduce computational requirements.

2. Short Circuit Program Description

A. General Description

The short circuit program employs the Z_{Bus} network formulation thereby enabling a Thevenin equivalent network to be computed at a faulted bus. Fault currents and corresponding node voltages are then determined using the Thevenin equivalent circuit. The basic assumption employed in this procedure is that load currents are negligible with respect to short circuit currents. With this assumption, if the network is described by

$$\underline{E}_{Bus} = Z_{Bus}\, \underline{I}_{Bus} \qquad 2.1$$

then the voltage change due to the fault is

$$\underline{E}_{Bus\ PF} - \underline{E}_{Bus\ F} = Z_{Bus}\, \underline{I}_{Bus\ F} \qquad 2.2$$

In the above:

$E_{Bus\ PF}$ = Pre-fault bus voltages

$E_{Bus\ F}$ = Post-fault bus voltages

$I_{Bus\ F}$ = Fault currents

Z_{Bus} = Bus impedance matrix

Thus, the network is represented as the composite Thevenin equivalent network shown in Figure 2.1.

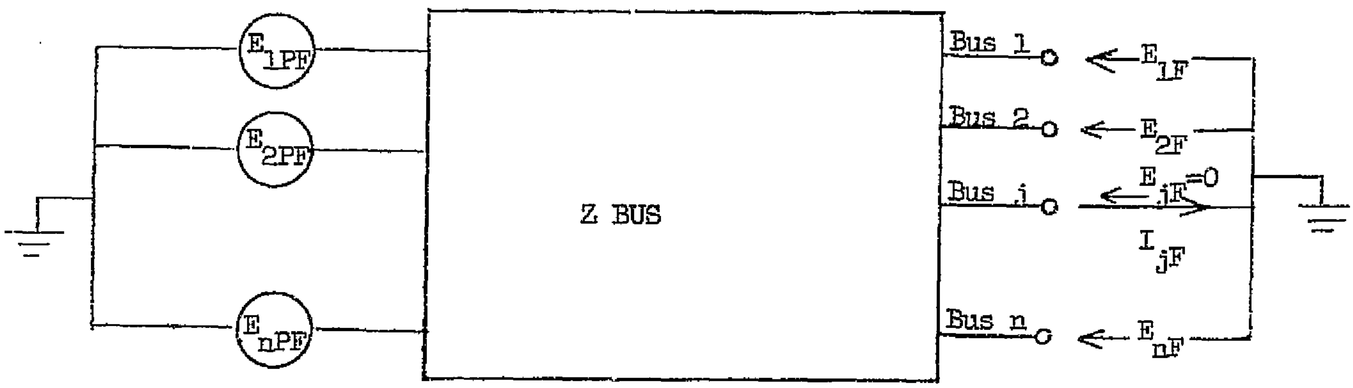


Figure 2.1 Thevenin Equivalent Network for Short Circuit Calculations

In Figure 2.1, it is assumed that bus j has been faulted (either three phase or single phase fault) resulting in fault current I_{jF} and $E_{jF} = 0$. Apply the fault condition at bus j to equations allows the fault current to be determined as

$$I_{jF} = \frac{E_{jPF}}{Z_{jj}} \qquad 2.3$$

Where Z_{jj} is the j-j element of Z_{Bus}, or the Thevenin equivalent impedance of the network as seen from bus j. Using equation 2.3 and equation 2.2, the post fault bus voltages and current flows between buses are obtained. The short circuit calculations is thus comprised of two computational procedures; one for determining the Z_Bus matrix for a given network configuration and the other for computing conditions resulting from a short circuit. Since the network Z_{Bus} is part of the overall computational algorithm, it is possible to alter the network after fault occurrence and compute conditions in the modified network. Thus, to aid in protection analysis, an optional computation is provided which sequentially disconnects one at a time all lines connected to the faulted bus and determines bus voltages and line flows under those conditions.

In the following, a more detailed description of these operations is given together with a functional diagram defining information flow in the program.

B. Network Z_{Bus} Assembly

A substantial portion of the short circuit calculation is concerned with developing the appropriate impedance matrices in a computationally efficient manner. In a substantially radial network such as that at KSC,

the Z_{Bus} matrix is very sparce, i.e. contains a large number of zero elements. That is, buses in a given radial are connected to buses in another radial only at the reference or supply bus. Furthermore, Z_{Bus} is symmetric since the impedance between connected buses is bilateral. Therefore, only elements of Z_{Bus} which are on and above the main diagonal and which directly affect the desired output need to be stored. The first task accomplished by the program then is to sort the input network data to define those elements and store them for use in assembly of Z_{Bus}. A retained bus list is compiled which lists the set of network buses together with all buses connected to each. Thus, when a particular bus is faulted, only those elements of Z_{Bus} which are required to compute line flows to connecting buses are employed.

The Z_{Bus} matrix is assembled sequentially by adding (or subtracting) impedances associated with network lines, one line at a time. Let $Z_{Bus\ P}$ represent the partial network bus impedance matrix and $Z_{Bus\ M}$ represent the modified matrix after the addition (or deletion) of a line. The modified matrix is obtained from the partial matrix by addition (or deletion) of a row and column. Two cases occur; when the additional line is a radial line whose terminal bus is not included in the partial network, and addition of a line whose terminal bus is included in the partial network. The latter case amounts to closing a loop in the network (providing dual feed to a load). Two different algorithms are employed.

For the addition of a radial line, assume that the partial network has n buses so that

$$Z_{Bus\ P} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} \\ Z_{12} & Z_{22} & & Z_{2n} \\ \vdots & & \ddots & \\ Z_{1n} & & & Z_{nn} \end{bmatrix}$$

Let the additional line have impedance Z_{nm}

Then

$$Z_{mm} = Z_{nm}$$

And

$$Z_{Bus\ m} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1n} & 0 \\ Z_{12} & Z_{22} & \cdots & Z_{2n} & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ Z_{1n} & Z_{2n} & \cdots & Z_{nn} & 0 \\ 0 & 0 & \cdots & 0 & Z_{mm} \end{bmatrix}$$

Thus, the modified matrix is simply one higher in dimension with one additional diagonal element.

For addition of a line which closes a loop, the initial and terminal buses of the line are both in the partial network. Thus, the modified matrix and the partial matrix have the same dimension. The modification thus requires changes in partial matrix elements. Assume the line is to be added between buses p and q. The changes are accomplished according to

$$Z_{ijm} = Z_{ijp} - \frac{Z_{il} Z_{lj}}{Z_{ll}} \qquad 2.4$$

$$i, j = 1, 2 \ldots . n$$

The change elements Z_{il}, Z_{lj}, Z_{ll} are defined by

$$Z_{il} = Z_{li} = Z_{pi} - Z_{qi} \qquad 2.5$$

$$i = 1, 2 \ldots n \quad i \neq l$$

$$Z_{ll} = Z_{pl} - Z_{ql} + Z_{pq} \qquad 2.6$$

Where

Z_{pq} = impedance of added branch
Z_{pi} = partial matrix element in location p, i
Z_{qi} = partial matrix element in location q, i

Thus, the system bus impedance matrix may be computed sequentially by adding elements in accordance with the network structure. Lines are removed by using the above algorithms to add a line with impedance equal to the negative of the impedance of the line to be removed.

Since both single phase and three phase fault conditions are computed, symmetric components are employed. Thus two Z_{Bus} matrices, the positive sequence matrix and the zero sequence matrix, must be compiled. Essentially the same computational procedure is used for each. Interconnection between buses is different for zero sequence from that of the positive sequence due to the existence of Delta connected transformers. Thus, either the retained bus list must be modified for zero sequence, or the input data must be arranged to reflect the different connection constraints. In order to minimize computational complexity, the latter approach is employed in the short circuit program. If buses p and q are connected for positive sequence currents but not for zero sequence, then the positive sequence line impedance is Z_{pq_1} and for zero sequence is given in the input data as

$$Z_{pq_0} = \infty$$

C. Short Circuit Calculations

The short circuit calculations follow from equations 2.2 and 2.3. If bus q is to be considered, then both single phase and three phase fault constraints are imposed and resulting currents and voltages are computed. Table 1 below summarizes computations for each case

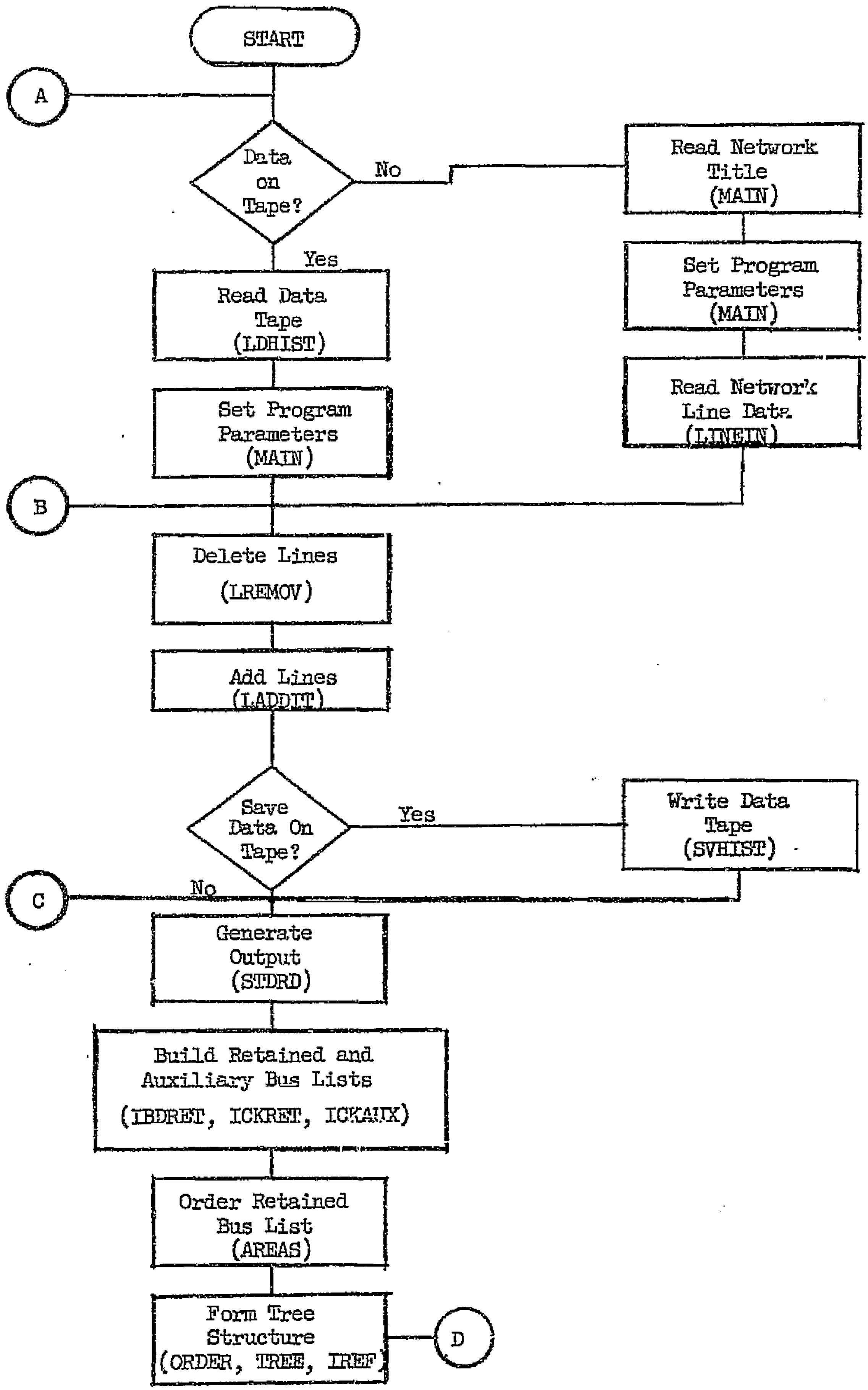
Type Fault	Single Phase Fault	Three Phase Fault
Fault Constraint	$E_{aq} = 0$	$E_{aq} = E_{bq} = E_{cg} = 0$
Sequence Fault Current	$I_{qF_1} = \dfrac{E_{qPF}}{Z_{qq_0} + 2Z_{qq_1}}$ $I_{qF_0} = I_{qF_1}$	$I_{qF_1} = \dfrac{E_{qPF}}{Z_{qq}}$ $I_{qF_0} = 0$
Total Fault Current	$I_{aF} = 3I_{qF_1}$	$I_{aF} = I_{qF_1}$
Bus Voltage During Fault	$E_{jF_0} = Z_{jq_0} I_{qF_0}$ $E_{jF_1} = E_{qPF} - Z_{jq_1} I_{qF_1}$	$E_{jF} = E_{jPF} \left(1 - \dfrac{Z_{qj}}{Z_{qq}} \right)$
Flow Between Bus i and Bus j	$I_{ij_0} = \dfrac{E_{jF_0} - E_{iF_0}}{Z_{oj_0}}$ $I_{ij_1} = \dfrac{E_{jF_1} - E_{iF_1}}{Z_{ij_1}}$ $I_{ij_a} = 2I_{ij_1} + I_{ij_0}$	$I_{ij} = \dfrac{E_{jF} - E_{iF}}{z_{oj_1}}$

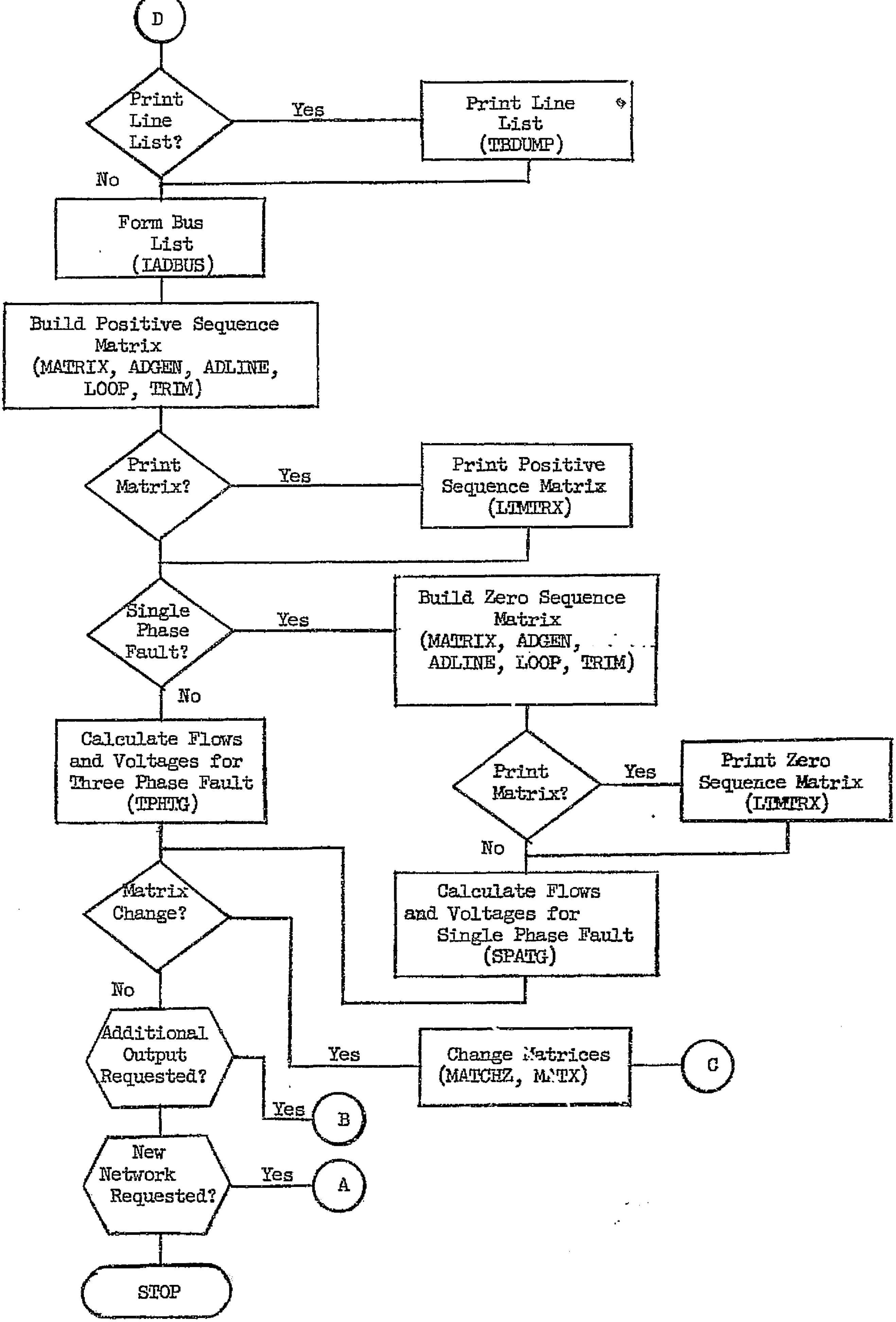
Table 2.1 Short Circuit Computation Algorithms

In the above table, the notation is used that subscript PF indicates pre-fault condition; subscript F indicates condition during fault; subscript o indicates zero sequence; subscript 1 indicates positive sequence; subscript a indicates phase a; upper case Z_{ij} indicates elements of Z_{Bus}; lower case z_{ij} indicates line impedance between bus i and j.

In the event that more than one line is connected to a faulted bus, the option exists to sequentially open the connected lines one at a time and compute the resulting network conditions. The algorithms for those computations are the same as in Table 2.1 except the bus impedance elements are replaced by modified elements in accordance with the deleted line.

The option exists in the program of either computing fault conditions at a single bus or sequentially computing fault conditions for each bus for all network buses.


START
A
Data on Tape?
No
Yes
Read Network Title (MAIN)
Set Program Parameters (MAIN)
Read Network Line Data (LINEIN)
Read Data Tape (LDHIST)
Set Program Parameters (MAIN)
B
Delete Lines (LREMOV)
Add Lines (LADDIT)
Save Data On Tape?
Yes
Write Data Tape (SVHIST)
No
C
Generate Output (STDRD)
Build Retained and Auxiliary Bus Lists (IBDRET, ICKRET, ICKAUX)
Order Retained Bus List (AREAS)
Form Tree Structure (ORDER, TREE, IREF)
D


D
Print Line List?
Yes
Print Line List (TBDUMP)
No
Form Bus List (IADBUS)
Build Positive Sequence Matrix (MATRIX, ADGEN, ADLINE, LOOP, TRIM)
Print Matrix?
Yes
Print Positive Sequence Matrix (LTMTRX)
Single Phase Fault?
Yes
Build Zero Sequence Matrix (MATRIX, ADGEN, ADLINE, LOOP, TRIM)
No
Calculate Flows and Voltages for Three Phase Fault (TPHTG)
Print Matrix?
Yes
Print Zero Sequence Matrix (LTMTRX)
No
Calculate Flows and Voltages for Single Phase Fault (SPATG)
Matrix Change?
No
Yes
Change Matrices (MATCHZ, MATX)
C
Additional Output Requested?
Yes
B
New Network Requested?
Yes
A
STOP

3. Input Data Preparation

A system network diagram should be available which includes all buses and impedance values. If the single phase to-ground option is used, a zero sequence network diagram is also needed.

All buses must be named with a unique name or number. The first letter of the bus name signifies the bus voltage as follows:

Bus Voltage	First Letter of Name
13,800	A
4,160	B
480	C
208	D
115,000	E
13,680	F
13,320	G
13,200	H
2,400	J
120/240	K

The bus names may contain up to six characters. The output will be generated in alphanumeric sequence. The reference bus must be named "SOURCE". The word "SOURCE" has been reserved for ground. Once the name has been established, it must always be referred to by that name---column for column, including blanks.

Special consideration must be given to the equivalent representation of transformers, since the positive and zero sequence network diagrams may be different. If this is the case, both network diagrams must be made to correspond to each other. If a node exists in only one network, the corresponding network can be made equivalent by inserting a corresponding node and inserting an impedance element large enough to eliminate any flow in the line that is missing. That is, an infinite impedance (9999.) should be given the missing line.

Impedance data base conversion is available to the user. For the Industrial Area, the impedances are calculated on a 13.8 Kv base, but the base voltage is actually 13.2 Kv. Therefore, the impedances for the Industrial Area must be multiplied by a factor 1.0454545. This is accomplished by inserting a card punched "*MISCELLANEOUS" followed by a card with 1.0454545 punched in holes 11-20. This causes the computer to multiply each impedance by 1.0454545 as the cards are read into the computer. Location and use of this card is explained in paragraph 4.

It is recommended that a degree of caution be exercised in preparing data for the program. The range of actual impedance data should not

exceed 500 to 1. The definition of actual impedance data is any line in which a flow is expected to occur. If a line flow is expected to be eliminated with the use of a large impedance value, as in some transformer applications, this impedance value should be at least 500 times the largest actual impedance value. The above ratios are only guidelines and should be used as such.

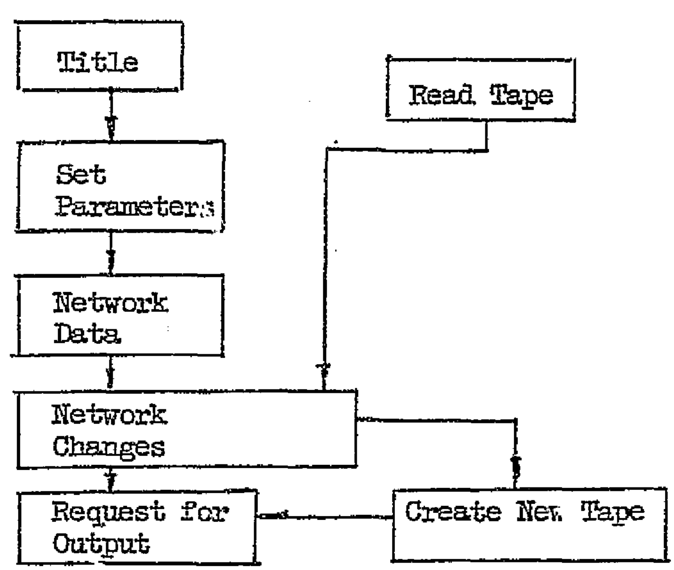
Each line must also be assigned a circuit number (0-15). This number is used along with the two bus names to identify the line. Therefore, parallel lines can be distinguished. Since the circuit number may not be greater than 15, if more than 16 lines connect two buses, an artificial bus must be created with zero impedance to one of the existing buses. If no circuit number is assigned, the computer automatically assigns the number zero.

The above data is placed on data cards in the following format:

Card Column	Description
1-6	Bus name (sending bus)
13-18	Bus name (receiving bus)
25-32	Positive sequence resistance in per unit
33-40	Positive sequence reactance in per unit
41-48	Zero sequence resistance in per unit
49-56	Zero sequence reactance in per unit
61-62	Circuit number

4. Program Utilization

The data is read into the computer in logical blocks. Each block of data is preceded by a program control card to inform the computer what information is contained on the following cards. The blocks of information should be organized in the following order:



Each of these blocks will now be described.

A. Title

This block will contain only two cards. The first card will be "*TITLE". This card tells the computer that the following card contains the title of the network about to be presented. The next card contains the title of the network in the first 72 columns of the card.

B. Set Parameters

This block is broken into two parts. Each part may or may not occur. If a block does not appear, a default value will be assigned to the parameters.

The first group of parameters that can be set contains the values of the MVA base and the input impedance constant. The first card in this part is "*MISCELLANEOUS". This card is followed by a card containing the MVA base in columns 1-10 and the input impedance constant in columns 11-20. The MVA base is set to 10 if this section does not appear. The input impedance constant is the value by which all input impedance values are multiplied as they are read. This number is set to one if this section does not appear. For the Industrial Area, the input impedance constant must be 1.0454545.

The second part of this block sets the following limits:

1) Maximum size of the retained bus list
2) Maximum size of the auxiliary list
3) Maximum number of buses
4) Maximum number of lines
5) Maximum dimension of the impedance array

These limits are set as follows:

First card-----"*SET LIMITS"

Second card-----

Column	Description	Default Value
1-10	Max. size bus list	40
11-20	Max size aux. bus list	200
21-30	Max. number of buses	1,000
31-40	Max. number of lines	1,000
41-50	Max. dimension impedance array	100

The default values represent the largest value these limits may be without program modifications. These numbers represent the size of various arrays in the program and have proven adequate for the existing network. If network expansion should require modification, these limits may be expanded by increasing the size of the following arrays in the program:

Array	Dimension
LSTRET	Max. size of ret. bus list
LSTAUZ	Max. size of aux. bus list
BNAME	Max. number of buses (not to exceed 2000)
LINE,X1,XO	Max. number of lines
LSTBUS	Max. dimension impedance array
Z1,ZO	(N+1)(N+2)/2, where N is the max. dimension of the impedance array

C. Network Data

This block contains the line data. The first card in this block is "*LINE DATA". The following cards contain the line data in the format presented in the previous section. The last card of this block must be "*END" to signify the end of the line data cards.

D. Network Changes

Either or both of the following changes may be made to the network:

a) Add lines---The first card in this section will be "*LINE ADDITIONS". This card will be followed by line data cards prepared as before. The last card will be "*END" to signify the end of the line additions.

b) Remove lines---The first card of this section will be "*LINE REMOVALS". This card will be followed by line data cards for the lines to be removed. The last card of this section will be "*END" to signify the end of the line removals.

E. Creating a Tape

At any point in the execution of a program, the network existing in the program may be saved on a history tape for future reference. This is done by inserting immediately after any of the blocks outlined previously a card with "*WRITE RECORD" in the first 13 columns of the card with the following additional information:

Card Column	Field	Definition
31-40	IC4	FORTRAN I/O device number on which the history tape reel for this study is mounted
41-50	IC5	Reel number of the tape mounted on the device IC4
51-60	IC6	Punch with any non-zero integer if this is to be the first record on the tape. This destroys anything that may have been on the tape previously. For saving records subsequent to the first case, this field is to be left blank. The program will count records and add the current record to the existing records and print a message indicating the number of the new record.

After the record has been saved by the program, a message is written on the output stating: " Data from previous case has been saved on tape___, reel number______, as record number____." The tape ____ indicates the logical device number of the output tape device.

A tape of the existing power system of the Kennedy Space Center has been produced. This tape is labeled "PWRSYS" and contains data for the Industrial Area as record one, and data for the Launch Complex as record two.

F. Using a Tape

Whenever it is desired to load the data from a case previously saved on a history tape (ex: loading the existing KSC network data) a "*RECALL RECORD" card is placed in the deck. This will cause the computer to read data previously stored on tape. This one card may accomplish the task of reading the title, setting the parameters, and entering the line data. However, if a different title or parameter set is desired, these blocks may be included after the "*RECALL RECORD" card.

This card is formatted as follows:

Card Column	Field	Definition
1-14	CNTR	"*RECALL RECORD"
31-40	IC4	FORTRAN I/O device number on which the history tape reel is mounted.
41-50	IC5	Reel number of the tape mounted on the device IC4.
51-60	IC6	Record number which is to be loaded.

G. Requesting Output

a) Basic Requests

The program has three different output modes for two types of fault conditions. The three modes are "SELECTED", "STANDARD", and "MODIFIED". When requesting output, one mode is combined with either "THREE PHASE" or "SINGLE PHASE" on an output request card to generate output for a three-phase-to-ground fault or a single-phase-to-ground fault respectively.

"SELECTED" output - This output mode enables the user to select the buses which are faulted. This will be the most common type of output since the user can request exactly the output desired. When requesting "SELECTED" output, the following cards are used "*SELECTED THREE PHASE" or "*SELECTED SINGLE PHASE". This card will be followed by cards specifying the buses to be faulted. The name of each bus to be faulted will be punched in columns 1-6, one bus per card. These cards will be followed by a "*END" card to signify that all faulted buses have now been specified. Any number of buses may be specified at one time. The program will fault the buses sequentially one at a time.

"STANDARD" output - This output mode sequentially faults all buses in the network in alphanumeric order. Only one card is required to request this output, i.e., "*STANDARD THREE PHASE" or "*STANDARD SINGLE PHASE" will create three-phase-to-ground or single-phase-to-ground faults for each bus in the network.

"MODIFIED" output - The "MODIFIED" output mode, like the "STANDARD" output mode, sequentially stepes through the network in alphanumeric order faulting the buses one at a time. However, rather than beginning with the first bus alphanumerically, the "MODIFIED" mode begins at the bus specified on the card following the card calling for "MODIFIED" output. (Example: card 1 - "*MODIFIED SINGLE PHASE", card 2 - "C209" — these two cards together call for the program to first fault bus C209 with a single-phase-to-ground fault, then fault sequentially all buses following bus C209 in alphanumeric order).

b) Output Options

The output modes described above may take any one of many forms depending on control variables that may be specified on an output request card. These control variables appear in columns 40, 50, 60, and 70. These control variables are described below:

IC4 - This variable is punched in column 40 of the output request cards. If IC4 is set to 1, the impedance matrix is printed each time it is computed. If IC4 is blank or zero, the matrix is not printed.

IC5 - This variable is punched in column 50 of the output request cards. The line flows will be output for this number of buses away from the faulted bus. For "SELECTED" output this number is specified for

each bus to be faulted in column 51 of the cards specifying the buses to be faulted. If this column is blank or zero, it is interpreted as 1.

IC6 - This variable is punched in column 60 of the output request cards. If IC6 is non-zero, the reordered line list (TREE STRUCTURE) will be printed each time the matrix is computed. A blank is interpreted as zero and no line list is printed.

IC7 - This variable is punched in column 70 of the output request cards. If this variable is zero or blank, the output will contain output for each faulted bus with each of the lines tied to that bus open. Any non-zero number supresses this feature.

H. Matrix Changes

An option exists in the program which allows the user to request changes to the positive and zero sequence matrices and ask for output. The matrix may be computed or called from a saved record. Remember, when using this option that the matrix must contain at least a small retained area that was computed previously. With this option, the user may remove lines, add lines, remove buses from the retained list, or ask for printing. Change cards may be in any order but must follow one of the following program control cards and terminate with a program control card punched "*END" in columns 1-4.

a) "*MATRIX CHANGES THREE" - This program control card makes changes to the positive sequence matrix only, and gives output in the three phase output format.

b) "*MATRIX CHANGES SINGLE" - This control card makes changes to both the positive and zero sequence matrices. The output is in single-phase-to-ground format.

If the user desires, he may first form a small matrix and then, by using the options explained here, he may build the matrix in the same way in which the program does in a normal run. The user may first add a line and then, if the bus is never used again, the bus may be eliminated from the matrix and another line added. This process can be repeated until all the lines are included for the system. It is not suggested that the user use this approach for large systems.

The input card format for matrix changes follows:

Card Column	Field Name	Description
1-6	NP	Bus name (sending bus)
13-18	NQ	Bus name (receiving bus)
25-56	X_1, X_o	Positive and zero sequence as on line data cards
60	NS	This is a code 1-5 which defines the action desired. 1. If a 1 is punched in column 60, this indicates the removal from the matrix of the line

described on the card. Both the sending and receiving buses must be in the retained bus list. Only the bus names and the circuit number are required in addition to the option code.
2. If a 2 is punched in column 60, this indicates that a line is being added to the existing matrix. One bus must be in the retained bus list in order to add a line and this must appear as the sending bus on the input card; all data is required for this card.
3. If a 3 is punched in column 60, this indicates to the program the elimination of a bus from the retained bus list. This means to the user that this is no longer available for further study. This bus name must appear as the sending bus. Only the bus name and option code are necessary on this card.
4. If a 4 is punched in column 60, this indicates that the user is asking for output. The bus which appears as the sending bus is faulted and output is given for as many buses as appear in the circuit number field. For example, if a 1 is punched in the circuit number field when using this option, the output will include the faulted bus and all lines connected to it. All lines will be opened around the bus and output given for this condition.
5. If a 5 is punched in column 60, this indicates that the user is asking for output as in 4 above. If this option is used, no lines are opened. Otherwise, 5 is identical to 4.

61-62	NC	This is used as the circuit number for types 1 and 2. On a type 4 change, NC is interpreted as N-back.

Note: It should be understood that a matrix change cannot be made immediately after reading in the line data because a matrix has not yet been

generated. The user must first call for output which would cause the matrix to be built. Once a change is requested, it does not actually become effective until output is again requested which causes the matrix to be recomputed. Output should be requested by using option 4.

I. Program Control Cards

This section contains a complete description of all program control cards required to implement the various phases of the Short Circuit Program. Most of these cards have been covered previously. For these cards, this section will summarize the information covered earlier. In addition to those cards previously mentioned, a number of less commonly used cards are also mentioned here. Those cards require no additional explanation other than that presented in this section. A command to execute a particular phase of the program is recognized by an "*" punched in card column one followed by one or more command words punched in card columns 2-24. Each command word must be separated by a blank and left justified in the field, starting in card column two. In addition to the command field, four other fields are provided. These fields are called control fields and are designated internally as IC4, IC5, IC6, and IC7. All control fields are ten columns wide and end in card columns 40, 50, 60, and 70 respectively. Data punched in these fields should be right justified.

1. *STANDARD THREE PHASE - This is a single control card which computes a three phase fault study. It gives output for all lines and buses connected directly to the faulted bus. If IC4 is set to 1 in column 40, the impedance matrix is printed each time it is computed. If a number is punched in IC5, column 50 of the program control card, the line flows will be output for that number of buses away from the faulted bus. If IC5 is zero or blank, it is assumed to be 1 and only the flows for the lines connected directly to the faulted bus will be printed. If IC6 is non-zero, the reordered line list (TREE STRUCTURE) will be printed each time the matrix is computed. If IC7, column 70, is non-zero the line-open feature is disabled.

2. *STANDARD SINGLE PHASE - This program control card is the same as in (1) except the output is computed for a single-phase-to-ground fault.

3. *MODIFIED THREE PHASE - This program control card is the same as in (1) except the output is not computed for all the buses. This card should be followed by a card containing a bus name in columns 1-6. This bus will be faulted and then all cards following in alphanumeric order.

4. *MODIFIED SINGLE PHASE - This program control card is the same as in (3) except the output is computed for single-phase-to-ground fault.

5. *SELECTED THREE PHASE - This control card should be followed by one or more data cards which must be terminated with the control card "*END". The data cards should contain, in columns 1-6, the name of the bus to be faulted. If the line flows for more than 1 bus away are desired, the number-back should be placed in column 51 of the same data card that names

the bus to be faulted. The program will compute the impedance matrix based upon the input cards. Only three phase output will be computed.

6. *SELECTED SINGLE PHASE - This control card is the same as (5) except only single-phase-to-ground option is computed and output. Note: For SELECTED THREE PHASE or SELECTED SINGLE PHASE options, any punches in cc 50 (IC5) are ignored. The number-back must be specified in cc 51 of each data card specifying buses to be faulted.

7. *DUMP LINE DATA - This is a single control which dumps out the line data that is in core at the time the control card is read and executed. If IC4 has a 1 punched in column 40, the ordered line list is printed rather than the sorted list. This will only be true if the matrix has been computed before this requested print.

8. *PRINT Z1 MATRIX - This is a single control which prints the positive sequence matrix at the time of request.

9. *PRINT ZO MATRIX - This control card prints the zero sequence matrix elements in the machine at the time of the request.

10. *LINE ADDITIONS - This control card should be followed by one or more data cards which must be terminated with a "*END". This control makes line additions to the line table already in the machine.

11. *LINE REMOVALS - This control expects other input data to follow and a card with "*END" punched in column 1-4 to terminate the action of this control. This control removes lines from the line data already in the machine.

12. *MATRIX CHANGES THREE - This control expects other input data to follow and must terminate with a card "*END" to terminate the action of the control. All data input under this card will only force change to the positive sequence matrix.

13. *MATRIX CHANGES SINGLE - This control card expects other input data to follow and must terminate with a card "*END" to terminate the action of the control. All data input under this control card will force change to the positive and zero sequence matrix. No mutuals will be involved using this option.

14. *LIST BUS - This control card prints the list of bus names in alphanumeric order and the bus numbers associated internally with each bus.

15. *LINE DATA - This control card expects the line data to follow and must be terminated with a card punched "*END" beginning in column 1.

16. *SET LIMITS - This control card expects only one card to follow. The next card will contain the following parameters: MAXRET (maximum size of retained bus list - columns 1-10), MAXAUX (maximum size of

auxiliary bus list - columns 11-20), MAXBUS (maximum number of buses - columns 21-30), MAXLI (maximum number of lines - columns 31-40), and MAXCOL (maximum number of buses in impedance matrix - columns 41-50). A blank or zero in any of these fields will be interpreted as "no change". These values are originally set to their maximum values of 70, 200, 1000, 1000, 100 respectively.

17. *MISCELLANEOUS - This control card expects only one card to follow. The next card will contain the following information: MVA base in columns 1-10, and the input impedance constant in columns 11-20.

18. *WRITE RECORD - This is a single control card and additional information must appear on the card. The logical I/O device number must be punched in the IC4 field, right justified. The reel number punched in the IC5 field, right justified. If the IC6 field is punched with a non-zero number, this will be the first record on the tape, but if left blank, the record will be added to the reel. If this is the first time to use the tape, IC6 <u>must</u> be non-zero.

19. *RECALL RECORD - This is a single control card with the necessary information to recall a Base Case. The logical I/O device number punched in the IC4 field, right justified. The reel number is punched in the IC5 field, right justified. The desired record number is punched in the IC6 field, right justified. If the IC6 field is left blank, an error message will be flagged.

20. *TITLE - Title card follows and prints as heading title. As many cards may be input as the user likes, but only the last card is retained in the machine for further use.

21. *REMARKS - Remarks card follows. Lists on output tape, single spaced. As many cards may be input as necessary, but one must be input with every remarks card. Only one card is read per control card.

22. *END - This control card is punched in columns 1-4 and must be used with some of the other control cards to terminate the action of that control card with which it is being used.

23. */ - This control is used to signify the beginning of an independent case and is a "do nothing" if read at any other time during input. Note: The start of a set of data cards for a case that is independent of the results of other cases should be marked by preceding the set of independent data with "*/" punched in column 1 and 2. The reason for this is that when the program detects an error, it searches for the next independent case by looking for a card with "*/" in column 1 and 2. It is not necessary to place this card in front of the first case. Several independent studies can be set up at a time with the use of history tapes. Each time a study is called from a history tape, this can be considered an independent study.

To obtain a clean ending for this program, control cards 22 and 23 are used together. Place the "*/" card followed by an "*END" card after all the data and program control cards. This signifies the end of the run.

J . Output Description

On the output the number of lines included in the system are printed along with the number of buses. The reference generator is also printed. This is the bus used to start building the matrix. It may be noted that when running a large study, this may change in the middle of the output. This means that the matrix has been computed more than one time and a different generator has been selected to start building the matrix.

On the output, the faulted bus will appear under the heading faulted bus. The total fault under FAULT and the driving point impedance under IMPEDANCE. Circuit number will appear just before the name of the other end bus. Under heading fault to bus will appear another bus name. This bus is the other end of the line leading away from the faulted bus. Under the heading voltage and flow will be the flow in the line and voltage at the bus appearing under the heading fault to bus. When a bus appears to the left of the bus under the heading fault to bus, this is the name of the opposite end of a line which is not connected directly to the faulted bus. Note: Voltage always applies to the bus under the heading fault to bus.

When asking for output two buses away from the faulted bus, output will include all lines two buses away from the faulted bus. If two buses are tied together with a line which are two buses away from the faulted bus, that line will appear in the output list. This is also true when asking for only one bus away from the faulted bus.

a) Three Phase Output

Three types of output may be requested for three phase. Standard output faults every bus and gives the flow in all lines a specified number of buses away from the faulted bus. Each line connected to the faulted bus is opened and the flows computed for the same number of buses away from the faulted bus. Selected output is the same as standard output except that only the requested number of buses are faulted. Output may be requested through the matrix changes and here the number of buses away from the faulted bus will include only those buses which are included in the retained area. Modified output is the same as standard output except the pass through the buses starts at the specified bus.

b) Single Phase Output

The output format for single-phase-to-ground is the same as three phase output except the calculations are different and more has been added. Under the heading IMPEDANCE, the equation is $2Z_{nn}(1) + Z_{nn}(o)$ and EZ is the zero sequence voltage at the faulted bus. Phase flow and $3I_o$ are printed for all lines when the bus is faulted. $3I_o$ is the three phase fault current. The voltage at the opposite end of all lines connected to the faulted bus is also printed.

K. Sample Decks

Presented here are two sample card decks. These decks represent two independent studies and are presented for illustration only.

a. The following sample card deck will read in the line information for a network with five lines and four buses. All buses are 480 volt base. The MVA base is 5. The network is titled "SAMPLE NETWORK." The output is standard three phase plus an additional output for a single phase fault on bus C3.

```
*TITLE

    SAMPLE NETWORK

*MISCELLANEOUS

5.

*LINE DATA

SOURCE       C1      .001     .18      .003     .02      0

C1           C2      .007     .13      .01      .101     0

C1           C3      .008     .151     .015     .091     0

C2           C3      .01      .05      .01      .07      0

C3           C4      .102     .231     .033     .1572    0
             ↑c-13   ↑c-25    ↑c-33    ↑c-41    ↑c-49    ↑c-62

*END

*STANDARD THREE PHASE

*/

*SELECTED SINGLE PHASE

C3

*END

*/

*END
```

a. The following sample card deck will read in line data from a tape mounted on the tape drive with logical device number 2. The first record on the tape will read. Two lines are then added and three phase output requested for buses B120 and B121.

```
*RECALL RECORD                    2         1         1
                                   c-40      c-50      c-60

*LINE ADDITIONS

B119     B120      .002      .013     .007     .025     0

B120     B121      .011      .025     .018     .033     0
         ←c-13     ←c-25     ←c-33    ←c-41    ←c-49    ←c-62

*END

*SELECTED THREE PHASE

B120

B121

*END

*/

*END
```

Appendix I COMPUTER PROGRAMS FOR ZERO SEQUENCE PARAMETER CALCULATIONS

Computer programs to calculate zero sequence impedances of 3 ϕ electrical cables with earth return using Fortran Language.

The following cards are common to all programs.

```
≥ CONTROL CARDS

        COMPLEX ZO, Z1, ZC
        DIMENSION LABEL (2)
        DATA DE, RE/10560., .286/
        DATA CONI/.8382/
        WRITE (6, 100)
        ZC = COMPLX (RC + RE, CONI*ALOG10(DE/GMR))
        GO TO 10
100     FORMAT (1H1, 20X, "IMPEDANCE PROGRAM" //3X,
    1   "LINE", 17X, "Z", 25X, "RC", 8X,
999     STOP
        END

≥ XQT
```

The value DE = 10560. = 880. * 12. represents the equivalent depth of the earth return path; RE = .2862 is the resistance in ohms/mile of earth return path and is independent of the depth of the return.

We will reproduce several basic programs and list the differences with similar programs.

A. PILC:

```
≥ CONTROL CARDS
≥ FOR, IS PILC

C       PROGRAM COMPUTES ZERO SEQUENCE IMPEDANCES OF
C       3 CONDUCTOR SHEATHED CABLES INSTALLED IN STEEL
C       CONDUITS (ZO) OR IN FIBER DUCTS (Z1) WITH EARTH
C       RETURN
C

        COMPLEX ZO, Z1, ZC
        COMPLEX ZS, ZP, ZCS, ZCP, ZSP, ZPMCP, ZCMCS
        COMPLEX ZCMCP, ZCPMSP, ZSMCS, ZCSMSP
        DIMENSION LABEL (2)
        DATA DE, RE/10560., .286/
        DATA CONI/.8382/
        DATA T, CR, CX/15.36, 29.9, 18.1/
        WRITE (6, 100)
10      READ (5, 101, END = 999) LABEL, RC, GMR, RS, ASH,
    1                                AP
        DP = AP*2.
        RP = T*CR*5.28/(DP*1000)
        XP = T*CX*5.28/(DP*1000)
        U = AP - ASH
```

```
      ZC = CMPLX (RC + RE, CONI*ALOG10(DE/GMR))
      ZS = CMPLX (3.*RS + RE, CONI*ALOG10(DE/ASH))
      ZPMCP = CMPLX (3.*RP, 3.*XP)
      ZCP = CMPLX (RE, CONI*ALOG10(DE/AP))
      ZCS = CMPLX (RE, CONI*ALOG10(DE/ASH))
      ZSP = CMPLX (RE, CONI*ALOG10(DE/U))
      ZP = ZCP + ZPMCP
      ZCMCP = ZC - ZCP
      ZCMCS = ZC - ZCS
      ZSMCS = ZS - ZCS
      ZCSMSP = ZCS - ZSP
      ZCPMSP = ZCP - ZSP
      ZO = ZS*(ZCMCS*ZPMCP + ZCMCP*ZCPMSP +
     1 ZSP*(ZCMCP*ZSMCS + ZCMCS*ZCSMSP) +
     2 ZCS*(ZPMCP*ZSMCS - ZCSMSP*ZCPMSP)
      ZO = ZO/(ZS*(ZP-ZSP) + ZSP*(ZS-ZSP))
      Z1 = ZC -(ZCS*ZCS/ZS)
      WRITE (6, 102) LABEL, ZO, RC, GMR, RS, ASH, RP, XP, AP
      WRITE (6, 103) Z1
      GO TO 10
999   STOP
100   FORMAT (1H1, 20X, "IMPEDANCE PROGRAM"//3X,
     1         "LINE", 17X, "Z", 25X, "RC", 8X,
     2         "GMR", 7X, "RS", 8X, "ASH", 7X, "RP", 8X,
     3         "XP", 8X, "AP"/
     4         16X, "REAL", 9X, "IMAGINARY"//)
101   FORMAT (A4, A6, 5F10.5)
102   FORMAT (1X, A4, A6, 2E15.5, 10X, 7F10.5)
103   FORMAT (11X, 2E15.5//)
      END

  ≳ XQT
PILC   500      .149      .6      .61      1.26      2.
```

B. BRNJ

```
  ≳ CONTROL CARDS
  ≳ FOR, IS BRNJ

C     PROGRAM COMPUTES ZERO IMPEDANCE OF 3 CONDUC
C     TOR OR 3 SINGLE CONDUCTOR NON-SHEATHED CABLES INSTALLED IN
C     STEEL CONDUITS (ZO) OR IN FIBER DUCTS (Z1) WITH
C     EARTH RETURN
C
      COMPLEX ZO, Z1, ZC
      COMPLEX ZP, ZCP, ZPMCP
      DIMENSION LABEL (2)
      DATA DE, RE/10560., .286/
      DATA CONI/.8382/
      DATA T, CR, CX/15.36, 29.9, 18.1/
      WRITE (6, 100)
10    READ (5, 101, END = 999) LABEL, RC, GMRIC, GMD, AP
      DP = AP*2.
      RP = T*CR*5.28/(DP*1000)
      XP = T*CX*5.28/(DP*1000)
```

```
      GMR = (GMRIC*GMD*GMD)**(1./3.)
      ZC = CMPLX (RC + RE, CONI*ALOG10(DE/GMR))
      ZPMCP = CMPLX (3.*RP, 3.*XP)
      ZCP = CMPLX (RE, CONI*ALOG10(DE/AP))
      ZP = ZCP + ZPMCP
      ZO = ZC - (ZCP*ZCP/ZP)
      Z1 = ZC
      WRITE (6, 102) LABEL, ZO, RC, GMRIC, RP, XP, AP
      WRITE (6, 103) Z1
      GO TO 10
999   STOP
100   FORMAT (1H1, 20X, "IMPEDANCE PROGRAM"//3X,
     1        "LINE", 17X, "Z", 25X, "RC", 8X,
     2        "GMRIC", 5X, "RP", 8X, "XP", 8X, "AP"/
     3        16X, "REAL", 9X, "IMAGINARY"//)
101   FORMAT (A5, A4, 4F10.5)
102   FORMAT (1X, A5, A4, 2E15.5, 10X, 5F10.5)
103   FORMAT (11X, 2E15.5//)
      END

   ≥ XQT
```

C. PIAC

```
   ≥ CONTROL CARDS
   ≥ FOR, IS PIAC

C     PROGRAM COMPUTES ZERO SEQUENCE IMPEDANCES OF
C     ONE 3C PIAC CABLE SUSPENDED FROM A MESSENGER
C     WITHOUT GROUND WIRES (ZO) OR WITH ONE GROUND
C     WIRE AT TOP OF POLE SPACED 66 INCHES FROM
C     MESSENGER (Z1) OR ONE 3C PIAC CABLE
C     INSTALLED UNDERGROUND IN FIBER DUCT (Z2)
C     PROGRAM ASSUMES THICKNESS OF ALUMINUM
C     SHEATH TO BE EQUAL TO THICKNESS OF THE LEAD
C     SHEATH OF ONE PIAC CABLE OF SAME VOLTAGE
C     RATING AND CONDUCTOR SIZE
C     PROGRAM ASSUMES MESSENGER AND GROUND
C     WIRES TO BE OF SAME SIZE AND MATERIAL
C
      COMPLEX ZO, Z1, ZC
      COMPLEX ZS, ZM, ZW, ZCS, ZCM, ZCW, ZSM, ZSW
      COMPLEX Z2, ZCMCS, ZCMCM, ZCMCW, ZSMCS
      COMPLEX ZCMMSM, ZCWMSW, ZCSMSM, ZCSMSW
      COMPLEX ZWMCW, ZMMCM
      DIMENSION LABEL (2)
      DATA DE, RE/10560., .286/
      DATA CONI/.8382/

      WRITE (6, 100)

10    READ (5, 101, END = 999) LABEL, RC, GMR, AW,
     1     OD, S, RW, RS, ASH
      GMRM = .779*AW
      GMRW = (.779*AW*66.)**(1./2.)
      DCM = ((OD - S * SQRT (3.)/3.)*(S*S/4. + (OD +
     1        S*SQRT(3.)/6.)**2.))**(1./3.)
```

```
      DSM = (ASH*ASH + (ASH + OD/2.)**2.)**(1./2.)

      DCW = ((66. + OD - S*SQRT(3.)/3.)*(S*S/4. +
     1       (66. + OD + S*SQRT(3.)/6.)**2.)*
     2       (OD - S*SQRT(3.)/3.)*(S*S/4. +
     3       (OD + S*SQRT(3.)/6.)**2.))**(1./6.)

      DSW = ((ASH*ASH + (ASH + 66. + OD)**2.)*
             (ASH*ASH + (ASH + OD)**2.))**(1./4.)
      RSA = .12067*RS
      ZC = CMPLX (RC + RE, CONI*ALOG10(DE/GMR))
      ZS = CMPLX (3.*RSA + RE, CONI*ALOG10(DE/ASH))
      ZW = CMPLX (3.*RW + RE, CONI*ALOG10(DE/GMRW))
      ZM = CMPLX (3.*RW + RE, CONI*ALOG10(DE/GMRM))
      ZCS = CMPLX (RE, CONI*ALOG10(DE/ASH))
      ZCM = CMPLX (RE, CONI*ALOG10(DE/DCM))
      ZCW = CMPLX (RE, CONI*ALOG10(DE/DCW))
      ZSM = CMPLX (RE, CONI*ALOG10(DE/DSM))
      ZSW = CMPLX (RE, CONI*ALOG10(DE/DSW))
      ZSMCS = ZS - ZCS
      ZCMCS = ZC - ZCS
      ZCMCM = ZC - ZCM
      ZCMCW = ZC - ZCW
      ZCSMSM = ZCS - ZSM
      ZCSMSW = ZCS - ZSW
      ZCMMSM = ZCM - ZSM
      ZCWMSW = ZCW - ZSW
      ZWMCW = ZW - ZCW
      ZMMCM = ZM - ZCM


      Z1 = ZS*(ZCMCS*ZWMCW + ZCMCW*ZCWMSW)
     1     + ZSW*(ZCMCW*ZSMCS + ZCMCS*ZCSMSW)
     2     + ZCS*(ZWMCW*ZSMCS - ZCSMSW*ZCWMSW)

      Z1 = Z1/(ZS*(ZW - ZSW) + ZSW*(ZS - ZSW))

      Z0 = ZS*(ZCMCS*ZMMCM + ZCMCM*ZCMMSM)
           + ZSM*(ZCMCM*ZSMCS + ZCMCS*ZCSMSM)
           + ZCS*(ZMMCM*ZSMCS - ZCSMSM*ZCMMSM)
      Z0 = Z0/(ZS*(ZM - ZSM) + ZSM*(ZS - ZSM))

      Z2 = ZC -(ZCS*ZCS/ZS)
      WRITE (6, 102) LABEL, Z0, RC, GMR, RS, RSA, RW, AW
      WRITE (6, 103) Z1
      WRITE (6, 103) Z2
      WRITE (6, 104)
      GO TO 10
999   STOP
100   FORMAT (1H1, 20X, "IMPEDANCE PROGRAM"//3X,
     1        "LINE", 17X, "Z", 25X, "RC", 8X,
     2        "GMR", 7X, "RS", 8X, "RSA", 7X, "RW",
     3        8X, "AW"//16X, "REAL", 9X, "IMAGINARY"//)
```

```
101     FORMAT (2A5, 8F8.4)
102     FORMAT (1X, 2A5, 2E15.5, 6F8.4)
103     FORMAT (11X, 2E15.5)
104     FORMAT (//)
        END

     ≅ XQT
```

D. XLPA:

```
     ≅ CONTROL CARDS
     ≅ FOR, IS XLPA

C       PROGRAM COMPUTES ZERO SEQUENCE IMPEDANCES OF
C       3 SINGLE CONDUCTOR CABLES SUSPENDED FROM A
C       MESSENGER WITH (ZO) OR WITHOUT (Z1) ONE GROUND WIRE
C       SPACED 66 INCHES FROM MESSENGER
C       PROGRAM ASSUMES GROUND AND MESSENGER
C       WIRES TO BE EQUAL SIZE AND MATERIAL
C

        COMPLEX ZO, Z1, ZC
        COMPLEX ZM, ZW, ZCM, ZCW

        DIMENSION LABEL (2)
        DATA DE, RE/10560 , .286/
        DATA CONI/.8382/
        WRITE (6, 100)
10      READ (5, 101, END = 999) LABEL, RC, GMRIC, S, RW,
      1      AW, OD
        GMR = (GMRIC*S*S)**(1./3.)
        GMRW = (.779*AW*66.)**(1./2.)
        DCM = 1.28*OD
        DCW = ((66. + OD - S*SQRT(3.)/3.)*(S*S/4. +
      1       (66. + OD + S*SQRT(3.)/6.)**2.))**(1./3.)
        DCW = (DCW*DCM)**(1./2.)
        ZC = CMPLX (RC + RE, CONI*ALOG10(DE/GMR))
        ZM = CMPLX (3.*RW + RE, CONI*ALOG10(DE/(.779*AW)))
        ZW = CMPLX (3.*RW + RE, CONI*ALOG10(DE/GMRW))
        ZCM = CMPLX (RE, CONI*ALOG10(DE/DCM))
        ZCW = CMPLX (RE, CONI*ALOG10(DE/DCW))
        ZO = ZC - (ZCW*ZCW/ZW)
        Z1 = ZC - (ZCM*ZCM/ZM)
        WRITE (6, 102) LABEL, ZO, RC, GMRIC, S, OD, RW, AW
        WRITE (6, 103) Z1
        GO TO 10
999     STOP
100     FORMAT (1H1, 20X, "IMPEDANCE PROGRAM"//3X,
      1         "LINE", 17X, "Z", 25X, "RC", 8X,
      2         "GMRIC", 5X, "S", 9X, "OD", 8X, "RW", 8X,
      3         "AW"/16X, "REAL", 9X, "IMAGINARY"//)
```

```
101     FORMAT (2A5, 6F10.6)
102     FORMAT (1X, 2A5, 2E15.5, 10X, 6F10.6)
103     FORMAT (11X, 2E15.5//)
        END
```

≚ XQT

E. RHWA:

≚ CONTROL CARDS
≚ FOR, IS RHWA

```
C       PROGRAM COMPUTES ZERO SEQUENCE IMPEDANCES OF
C       3-1C-CABLES + 1-1C-NUETRAL IN STEEL CONDUIT
C       (ZO) OR IN FIBER DUCT (Z1)
C
        COMPLEX ZO, Z1, ZC
        COMPLEX ZN, ZP, ZCP, ZCN, ZNP, ZCMCP, ZCMCN
        COMPLEX ZPMCP, ZCPMNP, ZNMCN, ZCNMNP

        DIMENSION LABEL (2)
        DATA DE, RE/10560., .286/
        DATA CONI/.8382/
        DATA T, CR, CX/15.36, 29.9, 18.1/
        WRITE (6, 100)
10      READ (5, 101, END = 999) LABEL, RC, RN, GMRIC,
       1     GMRN, S, AP
        DP = AP*2.
        RP = T*CR*5.28/(DP*1000)
        XP = T*CX*5.28/(DP*1000)
        GMR = (GMRIC*S*S)**(1./3.)
        ZC = CMPLX (RC + RE, CONI/*ALOG10(DE/GMR))
        ZN = CMPLX (3.*RN + RE, CONI*ALOG10(DE/GMRN))
        ZCN = CMPLX (RE, CONI*ALOG10(DE/S;))
        ZCP = CMPLX (RE, CONI*ALOG10(DE/AP))
        ZNP = ZCP
        ZPMCP = (3.*RP, 3.*XP)
        ZP = ZCP + ZPMCP
        ZNMCN = ZN - ZCN
        ZCPMNP = ZCP - ZNP
        ZCNMNP = ZCN - ZNP
        ZCMCP = ZC - ZCP
        ZCMCN = ZC - ZCN

        ZO = ZN*(ZCMCN*ZPMCP + ZCMCP*ZCPMNP)
             + ZNP*(ZCMCP*ZNMCN + ZCMCN*ZCNMNP)
             + ZCN*(ZPMCP*ZNMCN - ZCNMNP*ZCPMNP)

        ZO = ZO/(ZN*(ZP - ZNP) + ZNP*(ZN - ZNP))

        Z1 = ZC - (ZCN*ZCN/ZN)
```

```
      WRITE (6, 102) LABEL, ZO, RC, RN, GMRIC,
     1               GMRN, S, AP
      WRITE (6, 103) Z1
      GO TO 10

999   STOP
100   FORMAT (1H1, 20X, "IMPEDANCE PROGRAM"//3X,
     1        "LINE", 17X, "Z", 25X, "RC", 8X,
     2        "RN", 8X, "GMRIC", 5X, "GMRN", 6X,
     3        "S", 9X, "AP"/16X, "REAL", 9X, "IMAGINARY"//)

101   FORMAT (A4, A5, 6F10.5)
102   FORMAT (1X, A4, A5, 2E15.5, 6F10.5)
103   FORMAT (11X, 2E15.5//)
      END

   ≥ XQT
```

PARAMETER	COMPUTER PROGRAM	DETERMINATION
RC	PILC	Table of Cable Characteristics
	PIAC, BRNJ, XLPA, RHWA	Resistance Formulas for Positive Sequence
RN	RHWA	Resistance Formulas for Positive Sequence
RS	PILC, PIAC	Table of Cable Characteristics
ASH	PILC, PIAC	Table of Cable Characteristics
AW	PIAC, XLPA	Table of Conductor Characteristics
GMR	PILC, PIAC	Table of Cable Characteristics
GMRIC	BRNJ, XLPA, RHWA	Table of Conductor Characteristics
GMRN	RHWA	Table of Conductor Characteristics
OD	PIAC, XLPA	Table of Cable Characteristics
GMD	BRNJ	Reactance Parameters for Positive Sequence
S	PIAC, XLPA, RHWA	Equivalent to GMD as above
RW	PIAC, XLPA	Table of Conductor Characteristics and Resistance Formulas for Positive Sequence

References: "Transmission and Distribution Reference Book" by Westinghouse Electric Company
"Underground Systems Reference Book" by Edison Electrical Institute
"Electric Power Transmission" by Zaborsky and Rittenhouse
"Calculation Data For Wire and Cable" by Anaconda Wire and Cable Company
"Wire and Cable Selection and Technical Data" by General Electric Company
"Wire and Cable Data" by Rome Cable Company